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UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION MANUAL

Volume III Basin and Project Development

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PRELIMINARY LEGISLATION

.1 Although the Congress by passage of the Preemption Act of 1841 (5 Stat. 453), the Homestead Act of 1862 (12 Stat. 392), the Desert Land Act of 1877 (19 Stat. 377) and the Carey Act of 1894 (28 Stat. 422) had encouraged individual and private efforts in the direction of irrigation, there was a growing recognition of the need for Federal sponsorship. After bringing the issue to light in his first message to the Congress, President Theodore Roosevelt endorsed the major principles of a bill introduced by Representative Francis G. Newlands of Nevada. Following much debate, the bill, later to be popularly known as the Reclamation Act of 1902, passed both houses of the Congress and was signed by President Roosevelt on June 17, 1902.

RECLAMATION ACT OF 1902

.2 The Reclamation Act of June 17, 1902 (32 Stat. 388) provided for the examination, survey, and construction of irrigation works to reclaim the arid and semiarid lands of the West, appropriating for this purpose receipts (less specified deductions) from the sale and disposal of the public lands in the 16 states and territories of the arid region, this money constituting the "Reclamation fund." The Act conferred upon the Secretary of the Interior authority to enter into contracts for construction of irrigation works upon his determination that the irrigation project was practicable and providing that necessary funds were available in the Reclamation fund. The Act further provided for the entry of the reclaimed lands in accordance with the provisions of the homestead law, which was modified in certain important particulars, among them the following: That the settler must repay to the Reclamation fund within 10 years the cost of constructing the works necessary to reclaim the land he had taken; that the entry could not be commuted; and that the area of the entry must be limited to an amount not less than 40 nor more than 160 acres. The law applied to 16 western states--Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Utah, Washington, and Wyoming. On June 12, 1906 (34 Stat. 259), the Reclamation Act of 1902 was extended to the entire State of Texas. Within a few weeks after the passage of the Reclamation Act, the Secretary of the Interior ordered the creation of an organization to be called the Reclamation Service, later the Bureau of Reclamation, as the responsible agency for the administration of the Act. (Volume I, Chapter 1.1, contains a detailed history of the administrative organization of the Bureau.) On March 14, 1903, 6 major projects were approved by the Secretary, and a few months later on August 28, 1903, construction was begun on the first Reclamation project--the Truckee-Carson Project (now designated the Newlands Project) in Nevada. The following year, 1904, 5 more projects were authorized. In 1905, 9 more were authorized; in 1906, 4; and in 1907, 1; making a total of 25 projects for which construction was approved during the first 5 years. The Act of June 25, 1910 (36 Stat. 835) authorized advances to the Reclamation fund and among other things, provided that no new project was to be begun until it had been recommended by the Secretary of the Interior, and approved by the direct order of the President.

POWER DEVELOPMENT ON RECLAMATION PROJECTS

.3 In building irrigation works in the arid West, it was soon realized that large amounts of power were needed to provide power for pumping water for the irrigation of lands, and to operate construction machinery. Readily available was a source of power: The water to be conserved. Consequently, in 1906, Congress provided (34 Stat. 116, approved April 16, 1906), that whenever a power development was necessary for the irrigation of lands under a Reclamation project, or an opportunity was afforded for a power development under a project, the Secretary could lease for a period of not more than 10 years any surplus power or power privilege, giving preference to municipal purposes, provided that the lease would not impair the efficiency of the irrigation project. Very early in the application of the Reclamation Act it had become evident that a more comprehensive policy must be adopted in connection with the inclusion of privately owned lands. The Snake River Valley in Idaho, for instance, had great tracts of reclaimable vacant public lands, but there reclamation might have forced a large part of the population off land already brought under irrigation by pioneers. The solution was to permit the stored water to be shared by the privately owned lands instead of trying to use it wholly for irrigation adjacent tracts of public lands. On February 21, 1911, the Reclamation Act was amended accordingly by the Warren Act (36 Stat. 925) which authorized the sale of surplus water from a project for use on lands outside the project.

CHANGES IN RECLAMATION LAW BETWEEN 1914 & 1923

.4 An important change in the fiscal policy relative to Reclamation works was effected by the Extension Act of August 13, 1914 (38 Stat. 686). To meet the repayment difficulties experienced by many project settlers, the Act lengthened from 10 to 20 years the period of time for payment of construction charges. The Act provided also that after July 1, 1915, no expenditure should be made out of the Reclamation fund except by Congressional appropriation. Owing to restricted funds, only one new project had been undertaken by the Reclamation Service between 1907 and 1920. The lack of funds resulted from a decline in receipts from the sale of public lands combined with the comparatively small return from construction repayments resulting from the longer 20-year period repayment and from the necessity of setting aside $1,000,000 each year to repay a Treasury advance authorized in 1910. Section 35 of the Mineral and Oil Leasing Act approved on February 25, 1920 (41 Stat. 450), provided that 70 percent of the amounts received from oil royalties derived from public land oil leases, except those from Alaska, in the past and 52-1/2 percent of such receipts in the future be paid into the Reclamation fund. This was done to increase accretions to the Reclamation fund. Additional income to the fund was from receipts from potassium explorations and from Federal Water Power licenses.

MODIFICATION OF REPAYMENT POLICIES & PROCEDURES

.5 On May 15, 1922 (42 Stat. 541), contracts with irrigation districts for the repayment of construction charges were authorized, thereby shifting from the earlier requirements of contracts with individual water users and permitting releases of liens on individual lands under certain conditions. This Act enabled landowners on Reclamation projects to qualify for Federal land bank loans. Depressed farm prices and repayment difficulties of the early 1920's resulted in a review of national Reclamation. As a result, Congress enacted the Fact Finders' Act (43 Stat. 672 approved December 5, 1924). The Act provided that no new project or new division of a project should be approved for construction or estimates submitted therefor by the Secretary until the Secretary had secured detailed information concerning the water supply, the engineering feasibility, cost of construction, land prices, and probable cost of development; and had made a finding in writing that it was feasible, adaptable for settlement and farm homes and would probably return the cost thereof to the United States. It further provided for repayment of project construction charges in annual installments based upon 5 percent of the average annual acre income of the area in cultivation for the 10 calendar years first preceding, or for all years of record if fewer than 10. The Act also provided that whenever the water users of a project or division of a project take over operation and maintenance, the total accumulated net profits from powerplant operation, grazing or farm-land leases and the sale or rental of townsite land should be credited to construction charges against the project, and thereafter the net profits from such sources could be used, first, on account of project construction charges, second, on account of operation and maintenance charges, and, third, the net profits were to be used as the water users directed.

OMNIBUS ADJUSTMENT ACT

.6 The Act of May 25, 1926, the Omnibus Adjustment Act (44 Stat. 636), lengthened the repayment period from 20 to 40 years, and repealed the crop production plan of repayment in Subsection F of the Act of December 5, 1924 (Paragraph 1.1.5 above). Other provisions of the Act were that repayment contracts on new projects should be made only with water users' organizations and that a repayment contract covering the cost of construction must be entered into before water could be delivered. In the same Act, at the request of the Bureau which had encountered speculative abuses on project land, Congress also provided that irrigable project land in single ownership over 160 irrigable acres should not receive water unless a recordable contract was executed, providing for the sale of the excess land at not more than its appraised value.

BOULDER CANYON PROJECT ACT

.7 Reclamation policy was broadened and advanced when the President approved the Boulder Canyon Project Act on December 21, 1928 (45 Stat. 1057). The approval of this project, which called for the construction of the largest power plant in the world, signified a marked advance in the concept of reclamation. The sale of Boulder power at competitive rates was to pay the greater part of the cost of this first great multiple-purpose project. (An amendment later--July 19, 1940 (54 Stat. 774)--substituted an amortization basis for the

competitive rate basis of power sale in repayment of the project construction cost.)

.8 The National Industrial Recovery Act of June 16, 1933 (48 Stat. 195), which authorized an expenditure of $3,300,000,000 for public works resulted in great expansion of the construction program of the Bureau. Allocations of NIRA funds were made to irrigation projects. The vastly expanded program emphasized the necessity for increasing the number of sources from which flowed funds at a decreasing rate for reclamation. Owing to effective application of an oil conservation policy, the one important supplementary revenue to the Reclamation fund--the royalties received from the exploitation of oil on the public domain--was also diminishing. Accordingly, Congress passed legislation providing new revenues for the fund. The Hayden-O'Mahoney Amendment (52 Stat. 322) in the Interior Department Appropriation Act, 1939 covered into the Reclamation fund 52-1/2 percent of the total of all receipts, including penalties, received by the Treasury from lands within Naval oil reserves except those in Alaska, between February 25, 1920, and June 30, 1938. It also provided that all receipts from Reclamation projects, regardless of the source of the funds used for construction, except receipts from the Boulder Canyon Project or from projects where a different disposition had theretofore been provided by law or contract, should be covered into the Reclamation fund, with the proviso that power revenues received after the power allocation has been repaid shall go into miscellaneous receipts of the Treasury.

RECLAMATION PROGRAM EXPANDED

.9 Reclamation operations were further broadened by the Interior Department Appropriation Act, 1940 (53 Stat. 685), approved May 10, 1939, which made $5,000,000 available for allocation by the President to such Federal departments, establishments and agencies as he might designate for the purpose of constructing water conservation and utilization projects in the Great Plains and arid and semiarid areas of the United States as a measure of drought and work relief. By the President's designation, the Bureau of Reclamation was made the construction agency for such projects.

GREAT PLAINS LEGISLATION

The 1940 Appropriation Act required that the water users on such projects repay in not more than 40 annual installments the cost of construction met from appropriations under the Act. It also provided that the cost of labor or material supplied for such construction by the Work Projects Administration, Civilian Conservation Corps, or any other Federal agency should be repaid in such amounts and on such terms as the President might fix for each project. The Act of August 11, 1939 (53 Stat. 1418), as amended by the Acts of October 14, 1940 (54 Stat. 1119) and July 16, 1943 (57 Stat. 566) and called the Water Conservation and Utilization Act, authorized the Secretary to undertake the construction of similar projects on a similar repayment basis. Provision was made for cooperation by the Department of Agriculture, which was authorized to assist in project planning and assume land use and resettlement responsibilities.

.10 The activities which were carried on under the Great Plains Legislation and the Water Conservation and Utilization Act are being closed out as rapidly as possible by incorporation into the regular program. Only a very few of the original units constructed under these Acts are still being operated under the original or amended legislation.

REGULAR PROGRAM

.11 The Act of August 4, 1939 (53 Stat. 1187), known as the Reclamation Project Act of 1939, made it possible to adjust many difficulties of the water users, to draft new contracts gearing payments to the ability, year by year, of the farmers to make variable payments of construction charges, to reclassify lands from time to time, and to accomplish other needed reforms. The Act recognized the importance of power in determining the feasibility of a project. It provided that any sale of electric power or lease of power privileges should be for a period not longer than 40 years. In accordance with previous acts, preference in such sale and leases was to be given to municipalities or other public corporations or agencies, and no contract was to be made that would impair the efficiency of the project for irrigation. The provisions of the Act

RECLAMATION PROJECT ACT OF 1939

RECLAMATION PROJECT ACT OF 1939 (Cont.)

respecting the terms of sales of electric power and leases of power privileges were in addition and alternative to any authority in existing laws relating to particular projects. Changes were made in Sections 4, 7 and 17 of the Reclamation Project Act of 1939 by the Act of April 24, 1945 (59 Stat. 75), which result in extending the time within which amendatory repayment contracts may be negotiated and within which the Secretary of the Interior may grant deferments of construction charges. The foregoing changes also modify the operation of the normal and percentage plan by putting a ceiling on the amount that can become due in any year through the operation of the plan. Finally, where the execution of amendatory repayment contracts has been authorized, minor amendments may be made without further reference to the Congress. The Reclamation Project Act of 1939 established a broad foundation for the conservation and economic development of the water resources of the West. The cost of constructing multiple-purpose Reclamation projects is to be allocated equitably to the various authorized uses. An appropriate share of the construction cost may be allotted to irrigation but repayment by water users must be limited to that which can probably be repaid by the irrigation farmers within 40 years without interest. An appropriate share is to be borne by power for costs incurred for power features, and in addition, irrigation costs beyond the repayment ability of the irrigators may be assigned to be paid by net power revenues. The shares allotted to municipal water supply "and other miscellaneous purposes" are also reimbursable. Allocations may be made to flood control or navigation and are nonreimbursable under established national policy.

COLUMBIA BASIN PROJECT ACT

.12 In planning for the settlement and development of approximately one million acres of land in the Columbia Basin Project, the Bureau of Reclamation was faced with the problem of getting the land to the settlers at its reasonable value, without speculative increment on account of the prospective irrigation.

ANTI-SPECULATION ACT

.13 The Anti-Speculation Act of May 27, 1937 (50 Stat. 208) had proved inadequate. Consequently, the Congress enacted the Columbia Basin Project Act (57 Stat. 14) during the early part of 1943. This Act requires the owners of land in excess of specified acreages to sell the excess acreage at the value at which it is appraised by the Government. The appraisals are based on values before irrigation. Furthermore, owners who dispose of any holdings within 5 years after water is available must sell at not more than the appraised values. The Act also reauthorized the project as one subject to the Reclamation Project Act of 1939, the Grand Coulee Dam having been authorized under provisions of the River and Harbors Act approved August 30, 1935 (49 Stat. 1028). The 1943 Act authorized the Secretary of the Interior to acquire, sell, exchange, or lease project lands and adjacent land, to establish townsites, and to dedicate portions for public use, all in aid of and for the protection, development, or improvement of the project. In anticipation of taxing problems arising out of the acquisition of lands by the United States, the Act authorized the payment, out of funds derived from the lease of these lands, of money in lieu of taxes to the State of Washington or its political subdivision.

FLOOD CONTROL ACT OF 1944

.14 The Flood Control Act of 1944 (58 Stat. 887) accomplished four major purposes. First, it established certain policies and procedures that are designed to assure to the fullest extent that all states having an interest in proposed projects shall have adequate opportunity to express their views thereon and to have such views submitted to the Congress at the same time as reports recommending such projects are submitted to the Congress by the Secretary of the Army or by the Secretary of the Interior. Second, the Flood Control Act of 1944 protects the beneficial consumptive use of water west of the 98th Meridian against conflicting use for navigation by other works therein authorized. (Later enactments have extended this protection against other works as well.) Third, it assures that the use of water stored in reservoirs constructed subsequently by the Corps of Engineers shall be in accordance with the Federal Reclamation Laws; and, fourth, it provides that the Secretary of the Interior shall market power generated at reservoir projects constructed by the Army Engineers. In addition to the accomplishment of the above purposes, this Act approved and authorized the development of the initial stages of the Missouri River Basin by the Department of the Interior and the Department of the Army.

This Act also contained a policy expression by the Congress that had long been gradually developing, namely, "to facilitate the consideration of projects on a basis of comprehensive and coordinated development." This expression of policy by the Congress together with other acts providing for power development and the nonreimbursability of expenditures for flood control, navigation, and fish and wildlife at Reclamation projects pointed the way and permitted the Bureau to adopt its present policy of comprehensive basin-wide planning and development of water and related resources. The policies of the Bureau in this respect are developed in greater detail in following chapters.

FISH & WILDLIFE LEGISLATION

.15 The Act of August 14, 1946 (60 Stat. 1080) amended the Act of March 10, 1934 (48 Stat. 401), relating to the conservation of fish and wildlife resources. This statute provides for prior consultation with the Fish and Wildlife Service and affected state agency in order to promote effective planning, development, maintenance, and coordination of fish and wildlife conservation and rehabilitation whenever waters are authorized to be impounded, diverted or otherwise controlled by any department or agency of the United States or any public or private agency under Federal permit. The reports and recommendations of these consulted agencies are to be an integral part of any report submitted by the agency responsible for the planning or construction of such project. The law also authorizes the Secretary of the Interior, in addition to allocations of construction costs under provisions of the Reclamation Project Act of 1939, to make findings on the part of the estimated cost of the project which can properly be allocated to the preservation and propagation of fish and wildlife, such costs being nonreimbursable.

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GENERAL POLICY

.1 The policy of the Bureau of Reclamation is to work and cooperate closely with interested agencies in the investigation, construction, and operation of all of its projects. The nature and extent of the cooperation will vary in accordance with the various interests and with administrative and statutory requirements. It may follow the type of cooperation established between (1) the Department of Agriculture, the state agricultural colleges, and the Bureau of Reclamation relative to irrigation research and predevelopment farms in the Columbia and Colorado River Basins, (2) the Departments of Agriculture, Army, and Commerce, the Federal Power Commission, and the Bureau of Reclamation (Federal Inter-Agency Basin Committee) relative to watershed investigations and programs, or (3) it may follow the "Statement of Principles Relating to Cooperative Agricultural Research on the Reclamation Program in the Missouri Basin" adopted by the Department of Agriculture, the state agricultural experiment stations, and the Bureau of Reclamation. With respect to statutory requirements as set forth in the Soil and Moisture Conservation Act of 1935 (49 Stat. 163), the Fourth Plan of Government Reorganization (House Document 692, 76th Congress, 54 Stat. 1234, also see Chapter 8.1 of Volume V), and the Flood Control Act of 1944 (Public Law 534, 76th Congress), the Bureau, as an agency of the Department of the Interior, has been given specific responsibilities. Particularly, the 1944 Act establishes the Congressional policy on cooperation.

BASIC CONGRESSIONAL POLICY

.2 In the Flood Control Act of 1944 Congress declared it to be its policy "to recognize the interests and rights of the States in determining the development of the watersheds within their borders and likewise their interests and right in water utilization and control . . ." and "to facilitate the consideration of projects on a basis of comprehensive and coordinated development . . ." To effectuate these policies, the Congress provided in section 1(a) that:

" . . . Investigations which form the basis of any such plans, proposals, or reports shall be conducted in such a manner as to give to the affected State or States, during the course of the investigations, information developed by the investigations and also opportunity for consultation regarding plans and proposals, and, to the extent deemed practicable by the Chief of Engineers, opportunity to cooperate in the investigations . . . The Chief of Engineers shall transmit a copy of his proposed report to each affected State, and, in case the plans or proposals covered by the report are concerned with the use or control of waters which rise in whole or in part west of the ninety-seventh meridian, to the Secretary of the Interior. Within ninety days from the date of receipt of said proposed report, the written views and recommendations of each affected State and of the Secretary of the Interior may be submitted to the Chief of Engineers . . ."

The Congress provided in section 1(c) that:

"The Secretary of the Interior, in making investigations of and reports on works for irrigation and purposes incidental thereto, shall, in relation to an affected State or States (as defined in paragraph (a) of this section), and to the Secretary of War, be subject to the same provisions regarding investigations, plans, proposals and reports as prescribed in paragraph (a) of this section for the Chief of Engineers and the Secretary of War . . ."

POLICY OF THE SECRETARY OF THE INTERIOR

.3 Consistent with the above-stated policy of the Congress, the Secretary of the Interior, in a memorandum for bureaus and offices dated April 26, 1945, stated:

"The bureaus and agencies of the Department are instructed to work in close cooperation so that the programs of the Department will produce a comprehensive and coordinated development.

"The bureaus and agencies shall cooperate fully with the appropriate State officials and other Federal agencies in the exchange of data, participation in the investigations, and free discussion of the problems involved and possible solutions of those problems in any area under investigations, in a manner consistent with the intent of this law.

POLICY OF THE SECRETARY OF THE INTERIOR (Cont.)

"The bureaus and agencies shall keep in mind at all times and make clear to the officials of other Federal, State, or local agencies that the surveys and investigations upon which they are engaged and the plans and proposals which may evolve from such surveys and investigations are in a formative status, and after preparation in a tentative form, must be circulated for official review by the States affected and the other Federal agencies, as prescribed by the law and by Executive Order and Departmental Orders. Until I have approved and submitted the reports to the Congress with copies of such comments as are received in the course of their being circulated, they cannot be considered final."

ONE-PAGE STATEMENTS

.4 To carry out this policy of cooperation from the very inception of a project planning investigation, Regional Directors are requested to prepare a brief one-page statement (see Chapter 2.2) concurrent with the initiation of a water-resource development investigation, estimated to cost $10,000 or more, showing the scope of the investigation and the nature of the problems which appear to be involved. Through the appropriate distribution of these statements to all interested agencies within and outside of the Department, it is intended to afford opportunity for the desired cooperation.

RELATIONSHIP WITH STATES

.5 The Regional Director shall be responsible for effecting the proper cooperation and maintaining the desired relationship with the affected states. He, or his responsible field representative, shall personally contact the appropriate state officials prior to the formulation of his program of investigations, at the initiation of all investigations, and especially during the course of all investigations and preparation of planning reports. These initial contacts and periodic conferences should provide means of obtaining information on the states' interests and desires with respect to the development of river basins within their boundaries and likewise, information relative to their interests and rights in the utilization and control of these waters. Further, such conferences and discussions should be utilized as a means of furnishing the states with information developed by the investigations and will give opportunity for consultation regarding the Bureau's plans and proposals, or, as may be required, give the states opportunity to cooperate in the investigations. An interchange of information and ideas on investigations can also be frequently obtained through periodic reports to the states on progress of investigative work and expenditure of cooperative funds. It is frequently of advantage for the Bureau to conduct investigations cooperatively when state-contributed funds are made available to carry out necessary work which may not be done conveniently with Federal funds alone. Moreover, recent legislation requires that expenditures from Federal appropriations for investigations of any nature requested by states, municipalities, or other interests shall be upon the basis of these agencies advancing at least 50 percent of the estimated cost of such investigations.

OFFICIAL REVIEW OF PROJECT PLANNING REPORTS

.6 The official comments of the affected state or states and the Secretary of the Army will be obtained by the Commissioner of Reclamation, following the approval of a proposed project planning report and adoption of the report by the Secretary as his proposed report. The procedures connected therewith are described in Part 4.

OTHER CONGRESSIONAL POLICIES--FISH & WILDLIFE

.7 "In order to promote effective planning, development, maintenance, and coordination of wildlife conservation and rehabilitation," the Congress provided for particular coordination of wildlife matters pertaining to water resource developments in Public Law 732 (79th Congress). Existing Departmental and Bureau policies and procedures for effectuating this law are presented in Part 8 of Volume VII.

USE OF BUREAU RESERVOIRS--FLOOD CONTROL OR NAVIGATION

.8 Section 7 of the Flood Control Act of 1944 provides, in pertinent part, that:

"Hereafter, it shall be the duty of the Secretary of War to prescribe regulations for the use of storage allocated for flood control or navigation at all reservoirs constructed wholly or in part with Federal funds provided on the basis of such purposes, and the operation of any such project shall be in accordance with such regulations."

The Regional Director shall be responsible for negotiating with the Corps of Engineers to reach field agreement concerning such regulations. Final agreement will be subject to approval by the Commissioner. Policies and procedures to be followed are outlined in Part 8 of Volume IV.

IRRIGATION AT WAR DEPARTMENT RESERVOIRS

.9 Section 8 of the Flood Control Act of 1944 provides:

"Hereafter, whenever the Secretary of War determines, upon recommendation by the Secretary of the Interior that any dam and reservoir project operated under the direction of the Secretary of War may be utilized for irrigation purposes, the Secretary of the Interior is authorized to construct, operate, and maintain, under the provisions of the Federal reclamation laws (Act of June 17, 1902, 32 Stat. 388, and acts amendatory thereof or supplementary thereto), such additional works in connection therewith as he may deem necessary for irrigation purposes. Such irrigation works may be undertaken only after a report and findings thereon have been made by the Secretary of the Interior as provided in said Reclamation laws and after subsequent specific authorization of the Congress by an authorization act; and, within the limits of the water users' repayment ability such report may be predicated on the allocation to irrigation of an appropriate portion of the cost of structures and facilities used for irrigation and other purposes. Dams and reservoirs operated under the direction of the Secretary of War may be utilized hereafter for irrigation purposes only in conformity with the provisions of this section, but the foregoing requirement shall not prejudice lawful uses now existing. Provided, that this section shall not apply to any dam or reservoir heretofore constructed in whole or in part by the Army engineers, which provides conservation storage of water for irrigation purposes."

This provision of law thus, in practical effect, makes all irrigation activities related to reservoirs operated under the direction of the Secretary of the Army the responsibility of the Secretary of the Interior.

FEDERAL INTER-AGENCY RIVER BASIN COMMITTEE

.10 To permit agencies of the Department of the Army, Interior and Agriculture, and the Federal Power Commission, to cooperate more completely in the preparation of reports on multiple-purpose projects and to correlate the results to the greatest practicable extent, representatives of those agencies entered into a quadripartite agreement on December 29, 1943. This agreement established an "Inter-Agency River Basin Committee." In November 1946 the Department of Commerce was admitted to membership on this committee. Under date of December 29, 1943, the Committee established the following procedures to insure cooperation in the preparation of reports on multiple-purpose projects.

A. When investigations on multiple-purpose projects are ordered by any one of the above named agencies, each of the others will be notified.

B. Whenever the representative of one of these agencies shall determine that his organization has a direct responsibility in a project to be investigated by another agency, he shall notify the latter to that effect to insure that prompt contact is established by the field offices.

C. In all cooperative projects, the field offices will be instructed to communicate and confer with each other to:

(1) Determine what pertinent data are in existence and to arrange for the interchange of such data so as to avoid duplication of effort.

(2) Determine what pertinent data each agency intends to secure for its own purposes and to arrange a schedule which will avoid duplication and facilitate the concurrent submission of reports so far as practical.

(3) Arrange for the interchange of information throughout the preparation of reports. (Such interchange of information during the course of investigations and preparation of reports should take place at field level, or at regional or Commissioner's staff level as required for administrative decision.)

FEDERAL INTER-AGENCY RIVER BASIN COMMITTEE (Cont.)

(4) Arrange for conferences between field offices during the preparation of reports and when reports are completed and ready to forward. Each office is authorized to submit comments on the reports of other agencies, such comments to be forwarded with the reports.

Through the efforts of this committee at its regular monthly meetings and through the efforts of certain subcommittees (or task committees), mutual cooperation has been advanced in the investigational work of the Departments. The minutes of the meetings of the F.I.A.R.B.C. and the subcommittees thereof, which are available in the files of the Regional Directors, constitute a reference work on the activities of this committee.

MISSOURI & COLUMBIA BASIN INTER-AGENCY COMMITTEES

.11 The work of the Inter-Agency River Basin Committee was extended to provide for closer coordination of special problems by the creation of the Missouri River Basin and the Columbia River Basin Inter-Agency Committees on April 26, 1945 and February 5, 1946 respectively. The minutes of the meetings of these committees are available in the offices of the Regional Directors.

DEPARTMENTAL WATER RESOURCES COMMITTEE

.12 The Secretary, by Order No. 1946, dated May 2, 1944, directed the establishment of the Water Resources Committee for the purpose of coordinating the water development programs of the various agencies and bureaus of the Department of the Interior, and of providing a medium for effective Departmental liaison and clearance with other agencies concerned with water development programs. The membership of this Committee was made up by representation from various agencies of the Department who are concerned with the water resources development of the Nation. The Committee is charged with the responsibilities of (1) assembling essential information covering the water development programs of the bureaus and offices of the Department, and other agencies; (2) reviewing all basic projects or programs proposed to be undertaken by the bureaus and offices of the Department; and (3) formulating on the basis of the assembled information or the proposals reviewed, such recommendations as will insure an all-inclusive Departmental water conservation policy.

PROCEDURES

.13 The following procedures were prescribed to aid the Committee in the conduct of its work:

A. The bureaus and offices of the Department prepare and submit to the Committee reports covering all significant data on investigations in progress or planned to be undertaken with regard to the use of water and related natural resources.

B. The bureaus and offices of the Department submit to the Committee for its prior review proposals covering all basic water projects they desire to undertake, together with adequate explanatory data.

C. The Committee shall prepare for submission to other agencies concerned with water-development programs statements covering any aspects of these programs regarding which the Committee desires information including basic projects, programs and investigations planned, and significant data developed during or upon the completion of such activities. The Committee shall add to these statements requests for the advice of the agencies on those aspects of the Interior Department activities regarding which they correspondingly desire information.

D. The Committee shall systematically inform all bureaus and offices of the Department concerning all data so developed by the Committee that are relevant to their functions; and the Committee shall also furnish the other agencies that have requested information in response to the above statements all data consistent with the interests of the Department.

E. The Committee shall afford any agency the opportunity of appearing before it to make representations with respect to any unresolved or previously formulated questions of policy.

F. The recommendations formulated by the Committee on the basis of information assembled or work proposals submitted shall be concerned with factors or problems involving coordination between or among the affected agencies or bureaus, rather than with the internal technical soundness of any particular projects. The recommendations so formulated shall be submitted to the Secretary's Office for decision.

INTERIOR FIELD COMMITTEES

.14 In order to facilitate coordination at field level of the various bureaus and agencies of the Department, there were established the Interior Missouri Basin Field Committee and the Pacific Northwest Coordination Committee May 31, 1946 and September 26, 1946 respectively. The duties and responsibilities of these field committees are on a field level comparable to the Washington level of the Water Resources Committee and have a similar membership.

PUBLIC HEARINGS

.15 Public hearings can be used to evaluate the extent and character of local interest and public opinion in plans proposed for reclamation projects. They generally should be held by the Regional Director only after investigations have progressed sufficiently to indicate clearly and present adequately the possibilities of the development. Preinvestigation hearings, sometimes found to be desirable, should not be held unless the Bureau is prepared to proceed with investigations. It is also desirable that every agency whether Federal, state, or local be given an opportunity to participate in any hearings conducted by the Bureau of Reclamation. (See Part 6.)

.1 This part of Volume III traces the normal development of a project from the time it is conceived, through the various stages of investigations and construction, until it has become an operating unit. The types of investigations which are required to support the conclusions and recommendations leading to the authorization of specific units and approval of general basin plans are discussed in Chapter 2.2. Activities following authorization are outlined in Chapter 2.3. PURPOSE

.2 Nearly all of the investigations and reports of the Bureau are authorized under the Federal Reclamation Laws (Act of June 17, 1902, 32 Stat. 338 and acts amendatory thereof or supplementary thereto). While specific authority for the Secretary of the Interior to investigate irrigation features related to any dam and reservoir project, irrespective of location, operated under the direction of the Secretary of the Army is provided in Section 8 of the Flood Control Act of 1944, appropriations from the Reclamation Fund are not available for investigations outside the 17 Western States. AUTHORITY FOR INVESTIGATIONS

.3 Investigations and planning are financed through funds appropriated by the Congress, which are in some cases supplemented by contributions from states, municipalities, and other interests. Except when special investigations funds are appropriated for certain uses which preclude the use of General Investigations funds, and subject to the terms of the Appropriation Act making the moneys available, appropriations made for General Investigations are available for use in any of the 17 Western States for: APPROPRIATIONS

A. Engineering and economic investigations.

(1) Reconnaissance to determine whether a basin survey or a project investigation is justified.

(2) Comprehensive basin surveys to evolve a plan of development for utilization of the water resources of an entire river basin or subbasin.

(3) Investigations of potential projects, including individual new projects, or extensions of and additions to existing projects.

(4) General engineering and research studies not for a specific project, relating to reclamation development.

B. Advance planning. Detailed surveys and the preparation of Definite Plan Reports, plans, and specifications for projects authorized for construction for which project funds have not yet been appropriated by the Congress. Expenditures in this category shall be programed by the Regional Director only after he has submitted a specific justification for the work proposed and obtained written approval for it from the Commissioner.

C. Investigations of existing projects. Investigations and other activities on existing Federal Reclamation projects relating to:

(1) Financial adjustments.

(2) Rehabilitation surveys.

(3) Water conservation studies.

Appropriations for General Investigations should be used only for the investigations listed in the preceding subparagraphs and for the preparation or support, of reports relating to such investigations, unless otherwise specifically provided for in the language of the Appropriation Act. They should not be used for investigations of projects which are authorized for construction

APPROPRIATIONS (Cont.)

after construction appropriations have once been made available, except for investigations of existing projects already constructed (see Subparagraph C, above; see also Volumes XXIII and XXIV). Appropriations from the Reclamation Fund for General Investigations are limited to investigations in, or closely related to, the 17 Western States. Because of this, unless the studies are needed in connection with developments located in the 17 Western States, Reclamation Fund appropriations cannot be used to investigate irrigation features relating to Army dams, as provided for in Section 8 of the Flood Control Act of 1944, when they are outside of the 17 Western States. However, any unrestricted investigation appropriations from the General Fund may be used for such irrigation studies.

RESPONSIBILITY FOR INVESTIGATIONS

.4 Field investigations and surveys for planning purposes are generally performed by an operating office, under the direction of the Regional Director, in accordance with standards developed by the branches concerned. The Regional Planning Engineer is responsible to the Regional Director for the coordination of the technical phases of such investigations and prepares comprehensive reports thereon in cooperation with the Regional branches and offices which are responsible for the investigation and planning of specific components of a project development. The Regional Planning Engineer is also responsible to the Regional Director for the coordination of investigations with field representatives of other Federal agencies and with state and local agencies. However, when an investigation relates solely to a specific component of a project development, such as power or operation and maintenance, the Regional branch concerned with that function is responsible to the Regional Director for coordination with other agencies. ★In the case of work carried on under funds appropriated for general engineering and research, responsibility rests upon the Branch or Region to which the investigation is assigned.★

CHAPTER CONTENT

.1 The types of investigations undertaken by the Bureau prior to authorization are described in this chapter. There are several types of investigations, each of which leads to a report for a specific use. (See Part 4.) These are reconnaissance, project, basin, preconstruction, rehabilitation and financial adjustment, power planning and marketing, and special. Each will be covered in this chapter in the order named, except those relating to preconstruction activities and special investigations, which are discussed in Chapters 2.3 and 2.4.

PROCEDURE

.2 Investigations are initiated in several ways. The most common way is for an investigation to be requested by other Federal agencies, state, county, or municipal governments, or cooperating organizations. Such requests are examined by the Regional Director and, if they appear to have merit, a program for investigation is submitted to the Commissioner for approval. (See Volume XXIII.) Recent appropriation acts require that expenditures of General Investigation funds for investigations requested by states, municipalities, or other interests shall be upon the basis of the state, municipality, or other interest advancing at least 50 percent of the estimated cost of the investigations. Thus, when an investigation is undertaken at the formal request of local interests, a contract providing for financing not less than 50 percent of the estimated investigations costs must be made with those interests before the investigation is started. Another method of initiation is for the Congress to direct an investigation of a project or basin. Such direction is given in a resolution covering a definite area or project, or in the report of a Congressional committee. Regardless of the source of the request, investigations are conducted in the same manner in regard to quality and coverage, according to the type of investigation involved. (See Part 4.)

BASIC INVESTIGATION POLICY

.3 It is the basic policy of the Bureau to complete the field and office studies necessary to support adequately and conclusively the prescribed objectives of an investigation with a minimum expenditure of time and funds.

INVESTIGATIONS & LIMITATION OF EXPENDITURES

.4 Investigations conducted prior to authorization should be carried on to such point and in such detail as is necessary to determine whether the project under investigation has engineering and economic feasibility. When feasibility becomes apparent and authorization may be anticipated, investigations should be directed toward the requirements for a project planning report. In a similar manner, when infeasibility becomes apparent, preauthorization investigations should be continued only to the point necessary to show infeasibility under existing or foreseeable conditions.

A. On many projects, small and large, a reconnaissance type investigation will show beyond reasonable doubt that there is no plan that has engineering feasibility or that project cost is far beyond the range of economic feasibility. Where the reconnaissance report shows that reimbursable project costs cannot be repaid within a reasonable period of time, the investigation should be abandoned and a feasibility report is not prepared. In the event that after a regular project investigation has been begun, it becomes evident that a feasible project cannot, or should not, be developed, an unfavorable report will be prepared. See Chapter 4.8 for general guides for the preparation of unfavorable planning reports.

B. On investigations of large projects, where a small percentage of estimated construction costs represents very large preauthorization investigation costs, sound judgment will have to be used, in conjunction with readily available data, as the basis for certain estimates. The Bureau should not spend a large sum (for example, 5 percent of an estimated $50,000,000 project cost) investigating a project. Engineering, geologic, or economic boards and consultants properly may be used under such circumstances. Preauthorization investigations must be terminated at a reasonable point and, on large projects, seasoned engineering, hydrologic, and economic judgment and the best available safeguards for reliability of results necessarily must be substituted for finite and very detailed preauthorization

INVESTIGATIONS & LIMITATION OF EXPENDITURES (Cont.)

investigations. More detailed investigations, which are generally needed, should be scheduled immediately to follow authorization. (See Chapter 4.3.)

C. Very large projects usually involve policies peculiar to themselves and must be considered in the light of particular needs and circumstances. Where reasonable doubt as to feasibility of the major features exists, it is necessary to carry out sufficient investigations to make preliminary plans and estimates reasonably firm for obtaining authorization. Minor features may need to be investigated only so far as a reconnaissance study gives tangible form and substance to the plans.

D. Investigations should be sufficiently complete so that the total estimated cost of a contemplated project will be known with reasonable accuracy, but with the expectation that further and more detailed investigations might readily be expected to shift the distribution of the benefits and cost among the individual features of the project.

E. Chapters 2.6 and 2.7 of Volume V describe and establish minimum specifications for the three standard types of land classification and give the conditions under which each of them is applicable. The minimum specifications for a given type of classification are to be maintained but, if extensive areas are involved, the land-classification surveys in preauthorization investigations may be restricted to representative subareas and the results extended to the entire area. The other phases of economic investigations, such as land use and payment capacity determinations may be treated in a similar manner.

F. Standards in surveying and mapping are outlined in Volume VIII.

RECONNAISSANCE INVESTIGATIONS

.5 A reconnaissance investigation is primarily the investigation in which a potential development is first conceived and outlined in official form. It is the most easily made and usually least costly, of the several types. It requires, however, a great deal of advance planning, expert guidance, and competent review. A reconnaissance investigation is a study which enumerates all of the general information and basic facts on a given area, leading to a compilation of data in reports and maps, and involves a minimum of new field work essential to a decision to drop the investigation because of proof of infeasibility or to program further details and investigations. Reconnaissance investigations, because they are for the purpose of selecting development plans and project features, usually require only preliminary data and short-cut methods to reach a conclusion. Field and office activities, however, should be sufficient to support the preparation of cost estimates within reasonable accuracy. In applying this to a specific phase of a project such as, for example, an earth dam and appurtenant works, it is conceivable that the earth-fill portion of the structure may constitute less than half of the entire structure cost, while the spillway may comprise more than half of the cost. The accuracy of computations in connection with the spillway requirements then becomes a factor of major importance and any necessary corrections in the computations of these requirements might have a very appreciable effect on the total cost of the structure. In such a case, therefore, a detailed study of spillway requirements is desirable in order to verify the accuracy of preliminary studies and as a means of reducing the costs of such features, if possible. Conversely, if the spillway requirements are nominal but foundation conditions are the controlling factor, the studies should center about this latter condition, with a sufficient exploratory program to enable estimating within reasonable limits. Water supply and land classification are two of the more important features that should be considered in reconnaissance investigations. The findings of reconnaissance investigations are primarily for the use of the Regional Director in the furtherance of future studies. (See Chapter 4.4.)

A. Upon beginning a reconnaissance, the available data in respect to the area should be collected, studied, and analyzed so as to determine the most promising potential projects. A reconnaissance investigation should

consider every possible activity which the Bureau is authorized to undertake, and should recognize the interests of other Federal, state, and local agencies. An outline of the activities which should be considered is contained in Part 4.

RECONNAISSANCE INVESTIGATIONS (Cont.)

B. In the course of the studies of available data, some additional field work will be required to supplement or verify the data already at hand. Field work should be held to the least detail that will give the required information. Damsite profiles may serve in place of detail topography. Reservoir cross-sections or topography based on a reduced number of observations substitute for more accurate surveys. Stadia traverses with cross-slopes save the cost of strip topography or chained lines. Hydrological studies, involving the use of available data and preliminary estimates, should be sufficient to determine the approximate water supply available for development. Estimating curves are used to obtain comparative costs, and sampling procedures may be employed in land classification and economics.

C. All employees of the regional staff who have been assigned responsibilities in connection with investigations and planning reports should participate in the investigations to assure that all phases of the activities will receive proper recognition and that no major factors will be overlooked. As a result of the field and office studies, a report is prepared, based upon the available data, with recommendations as to disposition. (See Chapters 4.4 and 4.9.)

PROJECT INVESTIGATIONS

.6 Where a reconnaissance indicates that there are definite development potentialities which are consistent with overall basin plans, the programed investigations may proceed to establish firm information for authorization and construction appropriations. The investigations to be undertaken for this purpose should be sufficiently detailed to support adequately and conclusively the plans and estimates on all features of the project or unit. (See Paragraph 2.2.4B for details regarding the limitation of expenditures for project investigations.) The reconnaissance previously made indicates the approximate water supply available, the acreage which it will support, and the general plan for conserving the water and utilizing it for irrigation, power, or other purposes. (See Chapter 4.2.)

A. With this information at hand, a refinement of the hydrological studies previously made shall be undertaken. This item probably will not require any material change in conclusions if the original study was prepared properly, but the conclusions must be adequately supported and substantiated by detailed studies which demonstrate how the project will operate under representative and critical conditions. This phase is one of the most important in the project studies (see Volume IV). The success or failure of the project is basically dependent on land and on the water supply feature, both as to quality and quantity.

B. The degree of detail to be undertaken in connection with land classification will depend entirely upon the information available and the general characteristic of the soil and topography. (See Part 2 of Volume V.) It should be such, however, as to enable an accurate determination of the location and extent of the irrigable lands. If an adequate survey has been made during previous investigations, a review of such a survey by spot-check methods will suffice. However, if this is not the case, a detailed survey should be undertaken to define the limits and location of the project lands. Such a survey not only fulfills the requirements for the project proposal, but will also serve for later preconstruction surveys and planning and for operations.

C. A complete analysis of the power aspects of the project, including their relations to other plants and systems with which they are coordinated, must be accomplished to determine further the prospects of this feature and to coordinate power with the other functions of a multiple-purpose project. (See Volume VI.)

PROJECT INVESTIGATIONS (Cont.)

D. The degree of finality of engineering surveys should be sufficient only to support the required objectives. (See Paragraph 2.2.4 and Volume VIII.) On certain features of the investigations, these may vary from detailed surveys to rough flylines. It is probable that the greater portion of the topographic surveys will be of a detailed nature, since a comparatively small amount of additional time and labor are required to secure detailed information at the time of the original survey and the applicability of such a survey to the final requirements will make it the most economical method. Exploration programs to determine the foundation characteristics for major structures should be such as to verify surface observations and to provide sufficient information to enable the preparation of reliable preliminary plans and estimates. The materials exploration programs should be carried on under the same criteria. (See Volume XI.)

E. Upon the completion of the required land-classification and engineering activities, sufficient information is available to outline a plan for the development of the area and the preparation of a cost estimate. The plan is prepared in the field, district, or regional office; certain features of the cost estimates being prepared either by the Branch of Design and Construction or by the field office. Design and estimates should be accurate; consistent with the information at hand. (See Volume IX and Chapter 2.1 of Volume XXIII.)

F. With such a plan and cost estimate available, it is possible to integrate into the report the economic phases of the proposed development. It is expected that economic studies will have progressed sufficiently during the other activities of the investigation to enable arriving at a definite proposal. These studies include an estimate of the costs and benefits (Volume XIII), recommended cost allocations (Volume XIV), repayment requirements (Volume XV), procedures under which the project can be constructed, and provision for proper financial return as required by law. These items should be determined as definitely as possible, so that the Bureau can support them, subject to minor alteration or change following preconstruction surveys, in the first approach to landowners. However, information released prior to the planning report should be adequately qualified to avoid commitments in the event of changes for such reasons as revised costs or modification of plans.

G. A general census of the attitude in the affected area is a requisite in this stage of planning. The landowner's attitude has been a potential barrier to project development in some localities. This is especially true in areas which are dry-farmed and where a series of years of adequate rainfall has permitted a profitable return without irrigation. If an unfavorable attitude toward the development exists, the planning report may recommend that no further action be taken until the attitude has changed sufficiently to enable the formation of an irrigation district. This subject is not paramount in an area consisting predominantly of withdrawn public lands.

H. The importance of legal review during the investigation cannot be overemphasized. Legal review should not be deferred until the completion of a plan. Adequate legal review of the legal aspects of planning requires adequate legal investigation. Such investigation is an integral part of any planning investigation. Like other portions of the planning investigation, it is time-consuming. Adequate legal review also requires familiarity with the project being investigated. The conclusions drawn by Regional Counsel and his staff from their investigations may affect the course of other portions of a planning investigation.

I. The activities of other Federal and state agencies, particularly those of other Bureaus of the Department of the Interior, must receive adequate recognition in the planning and development of an area. (See Chapters 1.3 and 4.9.) Their proposals must be incorporated and integrated into the general plan to the extent practicable under the law. In many instances, features recommended by another agency cannot be incorporated into the

general plan because of the reimbursable nature of Reclamation funds. However, there are also many cases where a slight variation in plan will enable the full utilization of such recommendations at no additional cost.

J. Upon the completion of the necessary field and office work, all information on the project, including recommendations and basic data, is consolidated in the form of a project planning report (see Chapter 4.2). This report must be complete in every essential respect and contain data on the unit as it exists under present conditions and as proposed for development.

.7 It is not possible to outline a program of potential developments for the greatest good of the greatest number of people in an area until the task of comprehensive planning is viewed from a basin-wide perspective. It is requisite in all planning investigations that the area be looked at from a basin point of view in order to assure that a truly comprehensive picture has been outlined. This is especially so when the water supply is limited. There are very few basins in the West where the physical limitations on any possible development are not controlled by available water supply, although the possibility of trans-basin diversions is always present. With an inventory of all potentialities, it is possible to outline a comprehensive plan for the development of the natural resources of the basin. Existing project and reconnaissance investigations are a start toward basin planning. These investigations constitute an integral part of a basin investigation and should be incorporated into the general plan. They are supplemented by additional investigations, where required. The units of a basin plan of development which are recommended for initial authorization by the Regional Director should be investigated thoroughly and to the same general standards as project investigations (see Paragraph 2.2.6). These standards should be modified, as required, in accordance with instructions in Paragraph 2.2.4. The remainder of the basin, which comprises the deferred potentialities, shall be investigated in accordance with the standards for reconnaissance investigations. (See Paragraph 2.2.5.) BASIN INVESTIGATIONS

A. A decision based on sound engineering and economic judgment and full consideration of the desires and rights of the affected states must be made to arrive at a definite proposal for an area in question, when there are two or more potentialities or possibilities lying within a subbasin, all of which cannot be developed due to the limited water supply or land.

B. A basin plan must consider the interests, policies, and plans of all Federal agencies, the affected states, and other agencies, and the effect of these interests on the plan. (See Chapter 1.3.)

C. A basin-wide report contains a definite overall proposal for the area, which the Commissioner can transmit to the Secretary of the Interior for his consideration and, in the usual case, to the states of the basin, various Government agencies, and ultimately to the President and the Congress (see Chapters 4.2, 4.8, and 4.9).

.8 Construction of a project may be authorized: (1) by the Secretary of the Interior, or (2) by special legislation. AUTHORIZATION

A. For Secretarial authorization, the project must conform to the standards of feasibility provided in the Federal Reclamation Laws (Act of June 17, 1902, 32 Stat. 388 and acts amendatory thereof or supplementary thereto). An authorization by the Secretary may be made only upon the basis of a report which contains all the findings required by Section 9(a) of the Reclamation Project Act of 1939; conforms to the requirements of that section for feasibility; and meets with no objection from the Secretary of the Army or the states to which it must be sent for review in accordance with Section 1(c) of the Flood Control Act of 1944 (58 Stat. 887).

B. Authorizations by special legislation ordinarily result from the submission of project proposals to the Congress, including project plans which do not fully conform to existing requirements of the Reclamation Laws or which

AUTHORIZATION (Cont.)

have met with adverse comments from the Secretary of the Army or a state, or states. Infrequently, such authorizations result from the submission of basin-wide comprehensive plans for development. Where the authorization is on a project basis, it is confined to that specific project or to certain features of the project. In seeking authorization of projects, the overall objective of the project should be fully considered; not those of specific features alone. In the case of the basin-wide proposals, there may be included in the Regional Director's letter a request that the plan for the basin as a whole be approved and that certain features of the plan be authorized for construction. The features of a basin plan recommended for authorization will be those on which investigations have advanced to the point where the degree of feasibility is known and the studies have been undertaken in such detail as to enable a firm cost estimate and plan to be presented. (See Chapter 4.2.)

REHABILITATION & IMPROVEMENT

.9 The annual operation and maintenance costs on an irrigation project normally contain provision for routine maintenance of the irrigation system, including continuing rehabilitation work in the nature of repairs and replacements. However, after a project has been in operation for many years, and particularly following a depression or war, economical operation of the irrigation system may not be possible without taking care of an accumulated amount of major rehabilitation work. Therefore, special investigations are occasionally necessary on existing Reclamation projects, some of which have been in operation for many years, to determine the physical condition of the entire irrigation system, and need and cost of rehabilitation and improvement. Only on rare occasions do these investigations result in any changes in the project plan, and the reports are not commonly identified as planning reports unless it is necessary to obtain new or supplemental authorizations to undertake the work. The investigation may include seepage and weed surveys, as well as surveys of the condition of dams and reservoir areas, canal systems, pumping plants, and other structures. A rehabilitation survey may show the need for repairs to present structures, for replacement of deteriorated structures, for modernization of the system, or for replacement of operating equipment. Prior to a rehabilitation construction program, particularly when it involves any sizable expenditure of funds, a complete investigation is necessary. For a detailed account of the procedures for operation and maintenance of Reclamation projects, see Part 2 of Volume XVI.

FINANCIAL ADJUSTMENT

.10 Where need exists for amendatory repayment contracts, or when the water users have requested such contracts, the capacity of the water users to repay costs must be thoroughly examined. It is customary to prepare a comprehensive economic report (see Part 2 of Volume XV) on the basis of extensive investigations of existing project conditions; a repayment analysis; studies of the types of crops grown, credit standing of the farmers, adequacy of water supply, and the economic size of farm units; and a classification or reclassification of the productive capacity of the project. The negotiation of amendatory contracts calls for further investigations and preparation of reports and analyses as needed. These are considered as normal operation and maintenance functions, except when they are so extensive as to modify the project plan and require additional authorization, in which case they are considered predominantly as a planning matter. If the examination of a project indicates need for a general rehabilitation program and a survey and estimate of cost is made, the ability of the water users to repay the cost of rehabilitation construction must also be determined. Other items calling for investigation and financial adjustment in connection with existing projects, and in some cases on new projects, are: settlement of outstanding delinquent accounts; apportionment of operation and maintenance costs; temporary deferment of annual construction charges; and the causes and remedies of excessive operating costs. For a detailed discussion of the negotiation of amendatory repayment contracts, see Volume XV.

.11 Water conservation and development investigations are often related to the negotiation of amendatory repayment contracts for existing projects where irrigation is already practiced and, therefore, is a matter of routine operation and maintenance in most cases. However, when the proposed solutions would modify the plan of development or require new or supplemental authorizations, it becomes predominately a planning matter. These investigations include general surveys and analyses and reports of water uses, irrigation practices, and water losses for the purpose of developing better utilization of the available water on land. Included also are investigation of additional water supplies, groundwater elevations, present and future drainage needs, analyses of project operating methods, adequacy of operating equipment, and standards of irrigation service. Investigations may also be necessary to determine where the transfer of water rights should be made from inferior lands to more productive areas. For further details on water use and irrigation practices see Part 2 of Volume XVI.

WATER CONSERVATION & DEVELOPMENT

.12 In order to fulfill the requirement for adequate treatment, power studies for local and basin-wide reference are required. In the study of interconnection between basins and the transmission of power to industrial areas, it is necessary to prepare a special analysis and presentation of the power features including not only the generation and transmission of electrical energy, but also coordination of numerous power plans through an interconnected system and a study of markets and trends. Power planning studies make use of market studies, including those proposed by the Federal Power Commission and other Federal and Departmental agencies. (See Volume VI.)

POWER MARKETING & PLANNING

INTRODUCTION

.1 The steps which follow the authorization of a project, or division of a project, for which an appropriation has been made available may be divided into four phases:

A. Review of previous planning investigations.

B. Preconstruction or detailed investigations.

C. Construction.

D. Operation and maintenance.

REVIEW OF PREVIOUS PLANNING INVESTIGATIONS

.2 The review of previous planning investigations will depend upon two factors: (1) the length of time which has elapsed since these investigations were made and (2) the availability of employees who participated in the initial studies. If a relatively short time has elapsed and the same key employees are on hand to carry on the preconstruction activities, little, if any, review of previous studies will be required. However, if the opposite is the case, a study, review, and check of the basic information will be necessary to acquaint employees with the preceding investigations.

A. It may be desirable to conduct spot-check surveys at random points on the engineering and land-classification surveys for the purpose of checking preceding investigations and permitting the engineer in charge of the preconstruction activities to assume his full responsibility. Records and estimates should be brought up to date, and the information reviewed and verified for use in negotiations with the landowners in the project area, if irrigation is involved, and the project is not public lands.

B. A review of the landowners attitude is also essential at this time to ascertain the possibilities of forming an irrigation district and negotiating for a repayment contract in accordance with existing Reclamation Laws. If such is obviously impossible, further work on the project will not be desirable and construction thereof should be deferred until local attitudes are more favorable.

C. Upon the completion of these reviews, a memorandum of finding, containing pertinent information in relation to the project, with recommendations as to the procedure to be followed and the work program required to prepare the project for construction contracts, shall be prepared and submitted to the Regional Director.

PRECONSTRUCTION INVESTIGATIONS

.3 When, from information obtained in the planning investigations and its later review, it is clearly indicated that there are no basic obstacles either in the economic or engineering features of the project, intensive preconstruction investigations are in order to permit preparation of the Definite Plan Report before final plans and specifications are prepared and before construction contracts are let. (See Chapter 4.3.) At the same time, irrigation district formation, if not already under way, is initiated. Authorization is prerequisite to the initiation of preconstruction activities and the preparation of construction designs and specifications for any particular project. Only under specific authority of the Commissioner can such activities proceed prior to authorization. The details of the activities to be undertaken at this stage are not presented here as they are essentially the same as for detailed project investigations outlined in Chapter 2.2 and Part 4. The more important steps, however, are outlined briefly to set a general pattern.

A. Many of the engineering activities undertaken during the planning investigations are suitable for use at this stage of the project development. In particular this applies to the topographic surveys and other studies which were conducted with this later use in mind. Field engineering is confined to detailed surveys such as: (1) canal traverses and cross-sectioning, location of these alinements and appurtenant structures, (2) construction control for

PRECONSTRUCTION INVESTIGATIONS (Cont.)

large structures including dams, spillways, power and pumping plants, and transmission lines and facilities, and (3) land development and farm-unit surveys. The detailing of borrow areas for construction materials, access roads, highway, railroad and utility relocations, and necessary campsites is also required. Information in sufficient detail to permit the preparation of plans and specifications will be evolved during these operations. (See Part 1 of Volume IX.) In specific instances, authority for the preparation of designs and estimates on some features may be delegated to field offices. The Chief Engineer, or his designated representative, reviews the plans and the estimate of cost which are to appear in the Definite Plan Report. (See Volume XXIII.)

B. Activities in regard to land-classification surveys, development, and economic studies must receive detailed attention to support the final selection of the project area upon which the repayment contract is to be based. (See Volumes V and XV.)

C. During the preconstruction activities, the formation of an irrigation or conservancy district should be consummated under the state laws. (See Parts 5 and 6 of Volume XV.) This process requires considerable time and should not be delayed. The future of the project is dependent on this step and considerable effort will be required during the preconstruction period to furnish factual data to district officials in order that they may complete the formation of the district. District formation is applicable only where private lands occur and is not necessary at this stage where only public lands are involved.

D. When the irrigation district is formed, an organization exists with which to negotiate the repayment contract, a copy of which has previously been submitted to the Commissioner's office for clearance as to form. (See Volume XV.) Formal action, other than a definite indication from the district officers that they desire the project and are in general accord with the contract, is not required at this time. It is the experience of the Bureau that if a contract is reasonable and just, no real difficulties are encountered in its conditional acceptance by district officials. In numerous instances, however, questions are raised concerning minor details which may require explanation or revision.

E. In the meantime, all of the field information required for the preparation of final construction plans and specifications should have been transmitted to the Chief Engineer, so as to be in final form at the close of the negotiations with the district in order that a repayment contract can be promptly executed.

F. Upon completion of the preconstruction activities, a Definite Plan Report, which presents factual data and findings of these investigations, negotiations, and studies, is prepared. (See Chapter 4.3.) At this stage, the ground work of the project should be completed. The phases of project development which follow construction and operation and maintenance are not discussed in this chapter as they are treated in detail in Volumes X and XVI, respectively. Additional information on power development is also contained in Volume VI.

INTRODUCTION

.1 Sometimes investigations of specific phases of Reclamation development are required which have no definite relationship to a particular project, but which are applicable to the Bureau as a whole. Such investigations, which are conducted by or under the technical supervision of the Branch or Region having primary interest in the subject matter, are by no means subordinate to the general program which is being carried on by the Bureau, but are of vital importance to the solution of the problems with which they are concerned. These are broad general studies not connected with any one specific project although sometimes a portion of the study may involve work on a specific project to develop data needed for the general studies. A small portion of the funds in the general investigations program is allotted to general engineering and research.

TYPES OF INVESTIGATIONS

.2 Types of investigations included in "General Engineering and Research" are outlined for illustrative purposes in the following subparagraphs.

A. Power Studies. General studies of power generation, transmission and distribution to develop Regional power systems, new electrical equipment, high voltage transmission, coordination of systems, marketing of power and power rates, and preparation and interchange of technical data.

B. Hydrometeorological Studies. General studies of precipitation and storm analysis made in cooperation with the Weather Bureau or other agencies, and used in design flood studies required to appraise the possible flood flows that must be provided for in the design of dams and other hydraulic structures.

C. Cooperative Snow Investigations. General studies of the relationship between wind temperature and resulting snow melt and the amount of run-off that will be obtained, which are utilized to forecast future run-off.

D. Sprinkler Irrigation Studies. Studies of general application of sprinkler systems to irrigation.

E. Water Compact Commission Studies. General studies made by the Bureau in connection with the negotiations and studies of water compact commissions, etc.

F. Sedimentation Studies. General studies of methods of silt transportation and effects of sedimentation on life of reservoirs and other structures, and methods of providing for the handling of silt in hydraulic structures and systems.

G. Hydrologic Studies. General studies to prepare forecasts on outlook for water, prepare and interchange technical data with other agencies; studies of new scientific advances in the field of hydrologic research in order to determine possible effects on existing and potential reclamation projects.

H. Cooperative Crop Studies. General cooperative studies on irrigation and marketing of fruits and other specialized crops.

I. Project Benefit - Cost Studies. Study of methods of computing project benefits and costs to estimate benefit-cost ratio used in developing project plans, in comparing alternate plans of development, and in determining economic justification of projects.

J. Operation and Maintenance Cost and Replacement Analysis. Studies of operation and maintenance, and replacement costs to make more accurate analysis of costs of these features in planning for potential projects.

K. Ice Conditions. Studies or research for controlling and determining effects of ice on structures.

L. Construction Materials. General studies for the development of new or improved construction materials, or better utilization of materials such as cement, concrete, aggregates, and metals.

M. Canal Lining. General studies on new or improved methods and materials for canal lining, etc.

N. Special Hydraulic Studies. General studies or designs for and methods of handling water under high velocities in spillways, etc.

O. Weed Control. Research conducted in cooperation with the Bureau of Plant Industry, Soils and Agricultural Engineering on methods of weed control.

REIMBURSEMENT .3 As general engineering and research does not involve work done for a specific project, even though project facilities may be utilized, it is a general expenditure and such cost is nonreimbursable by law. Work done for a specific project cannot be classed as general engineering and research. However, it should be recognized that engineering and research of a seemingly general nature may be considered to be current design work in some circumstances, and, on approval of the program by the Commissioner, charged to specific projects.

Interior - Reclamation - Denver, Colo.

CHAP. 3.1 PROJECT SELECTION

INTRODUCTION

.1 The selection of projects involves the measurement in engineering and economic terms of the probable physical size and financial success of a proposed development before the Federal Government undertakes construction or commits itself to construction. Such a measurement, or series of comparative measurements and estimates, involves the investigation of land, water, energy, and related potential developments in light of potential needs, engineering feasibility, economic advantages, legal requirements and restrictions, popular support, and the rights and needs of projects existing in the area of study. Chapter 2.2 of this Volume contains much helpful material concerning such investigations during the formulation of project plans. Manual discussions in Volumes IV to VIII and X, XIII, XIV, and XV will be helpful in carrying out the many phases of technical work needed to select project plans and to develop them.

STEPS IN PROJECT SELECTION

.2 The selection of units or projects is involved in practically all project planning processes and procedures from the reconnaissance investigation to the more detailed investigations required for establishing the definite plan of development. Such processes require coordination and cooperation with all affected groups as well as making the purely objective surveys, studies, and analysis by the engineer and economist. All of this must be done in accordance with provisions of the Federal Reclamation Laws, and with policies of the Department and Bureau. The steps or procedures ordinarily involved in project selection are outlined as follows:

A. Need for the potential products or services of the project must be established.

B. Physical and economic possibilities for development are inventoried and analyzed.

C. The scope or scale of project development is established.

D. Priorities of development are determined.

DISCUSSION

.3 The selection of a project or unit plan may be fixed by existing conditions in the case of an independent irrigation district seeking Federal assistance to replace a weakened or destroyed dam under the provisions of the Reclamation laws, it may be wholly creative in the case of a new potential development, or it may be a combination of both. In most cases the planning engineer is faced with a large number of related or competitive conditions imposed by existing land and water resource developments operating under restrictive Federal and state water laws, and by fixed or desirable priorities of use. His problem is to develop a plan for the best utilization of all of the remaining resources. He may do this by adding to existing systems or facilities, or by constructing new ones. Usually some voluntary rearrangement in the existing ownership pattern through purchase or exchange will simplify the problem. Sometimes it may be necessary to seek changes in state laws to permit the necessary rearrangements.

The planning engineer is responsible for the initial selection of the units and the individual facilities to be used. This may necessitate development not merely of one plan, but several, and require exhaustive comparative computations. It will require consideration of the relation of the particular development to the over-all basin or area development. The number of possible combinations may be appalling, but fortunately the degree of acceptability usually is so marked that many combinations may be dropped at once as inferior, and the problem may be resolved shortly to a single plan or to two or three alternatives that must be studied in detail. Commonly the planning engineer is aided by a considerable number of previous investigations which have already eliminated some of the alternatives. Sometimes local proponents divide into factions, supporting opposing plans, which requires the planner to be a diplomat as well as an engineer. The selection of facilities which make up the plan for a unit or project is reached by a process of elimination using no greater amount of detail and expense than necessary to reach a conclusive decision. Decisions should be made only after conclusions are reached as to the most desirable specific features to fit the over-all optimum development.

COMPLEX ELEMENTS

.4 The same principals apply in selecting a plan of development as in selecting one or more projects from a large group of projects. For most projects, some scheme of development may already be worked out and championed by the local sponsors. While some new plan may well be adopted, it will usually be necessary to examine these earlier plans with careful consideration before proposing a new alternative. Sometimes the simplest plan is the best, but in many cases appreciable advantages are gained by introducing complex elements. A few examples will illustrate:

A. Separate diversion dams may shorten canal lines and afford better topography and geological conditions than diversions directly from storage reservoirs.

B. Pumping plants may be substituted for gravity systems to eliminate long reaches of expensive conduits to reach the project lands.

C. Diversions from adjacent watersheds may not only produce more abundant water supplies, but cheaper systems than utilization of local supplies.

D. Storage regulation may greatly reduce conduit capacity where there is large variation in either daily supply or daily demand.

E. Exchange of water with existing rights may permit development of cheap storage on tributaries or at downstream sites in lieu of expensive upstream storage, or avoid costly pump lifts and waste of water.

F. Canal linings or sprinkler systems may conserve water for additional areas, and at the same time eliminate the need for expensive drainage systems.

G. Water belonging to others may be diverted for power purposes and returned to the stream above points of delivery.

H. Power characteristics may be improved by system integration to take advantage of streams of different run-off characteristics, or by providing reregulation storage capacity.

I. Afterbay regulation may greatly improve firm power capabilities.

J. Full utilization of reservoir power head may sometimes be achieved by extending penstocks below the reservoir.

K. Where floods are seasonal in occurrence, reservoir capacity may be used jointly in sequence, for flood control and conservation purposes.

CRITERIA FOR SELECTION

.5 The measurement of projects against standards of acceptability should be made as early as possible in the investigations in order to minimize the study of those projects which obviously will fail upon complete investigation to meet qualification standards. The selection of a project for recommendation must meet certain minimum standards and, where alternatives are involved, the project selected should, as a rule, most favorably meet such standards. The following physical and economic criteria shall serve as general guides in selecting reclamation units for projects for detailed planning or for development: 1/

Quality of Land

A. There must be sufficient arable land in areas of such size and proximity to permit economic operations under irrigation using agricultural practices common to the vicinity or comparable areas. (See Volume V.)

Water Supply

B. A water supply for irrigation, power, or other purposes must be available in dependable quantity sufficient to warrant the expenditure necessary to

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1/ Some of these criteria will not be applicable to single project, but all of them are applicable to complex multiple-purpose projects.

utilize it in sustained economic operations, and in acceptable quality for the purpose used. (See Volume IV.)

C. Physical opportunity for engineering development must be present and sufficiently attractive to permit economical construction. That is, natural reservoir basins should customarily be available; dam sites must be structurally adequate; pump lifts and canal lengths should be within economic limits; topography and geology should permit of economical design, construction, and operation. — Facility Sites

D. The project or unit should not prevent the construction of other units of the basin plan for maximum economic development of water resources or adversely affect existing developments beyond an amount commensurate with the benefits. — Acceptability

E. The useful life of a project or unit depends upon many factors and should be carefully considered. Water supplies may be reduced by the encroachment of higher priority uses incident to population or industrial growth or overdraft of water resources including lowering of the water table below an economic pump lift. Reservoir capacity may be reduced and eventually destroyed by sedimentation, requiring provision of substitute storage at other sites, if available, or eventual adjustment of operations to the modified conditions. Soil productivity may be destroyed by excessive leaching, waterlogging or deposition of salts or sediments which permanently affect its permeability or workability. In any case, the useful life of the project should exceed the repayment period with a margin of safety to permit orderly adjustments to be made in the operations of individual water users without disaster. The minimum useful life ordinarily should be at least 50 years. (See Part 9, Sedimentation, of Volume VII.) — Useful Life

F. The estimated revenues from all project sources should be sufficient to pay for all reimbursable costs, in addition to operation, maintenance, and replacement costs. (See Volume XV.) — Repayment

G. Total project benefits must equal or exceed total project costs. (See Volume XIII.) Sometimes the project with the highest benefit-cost ratio is selected in preference to a more extended project with a lower ratio. Normally, however, the principle of optimum feasible development as the ultimate objective, should rule. — Benefit-Cost Ratio

H. The extent of development should be determined by the point at which the net benefits are at a maximum, or most nearly so as determined by some practical measurement. Net benefits are considered to be maximum when the extent of development is at the point where the benefits added by the last increment of the project scope are equal to the costs of adding that increment. — Scope

I. All selected projects must be able to meet operation, maintenance, and replacement costs, as a minimum. — O&M & Replacement

J. Maximum feasible power development, consistent with other priority of uses, is a requirement. — Power Development

K. The selected multiple-purpose units or projects should be more economical of development as a whole than other potential means for accomplishing the same aggregate benefits. — Economy of Development

.6 After a group of units or projects have been selected for further investigation or recommended for development, the priority of investigation or development must be scheduled unless sufficient funds, labor, and materials are available to undertake all of them. The priority of development should be determined by developing those units or projects first which best meet or fulfill the criteria outlined in Paragraph 3.1.5. Other matters which may influence priority of development include such items as the following: — PRIORITY OF DEVELOPMENT

Status — A. The nearness to completion of an investigation already under way is important. Unless the deficiencies of physical data require the accumulation of several years of records before an investigation already under way can be completed, it is usually advisable to complete the investigation even though the project may not be the best for final selection.

Urgency — B. High priority should be given to construction of a selected project which involves the reconstruction of features essential to prevention of disaster, physically or financially, in an established community, such as involved in the Preston Bench Project, Idaho.

Local Interest — C. Reclamation projects require a high degree of local support to make them successful because of the repayment features of the Federal Reclamation Laws, and for other reasons. A project selected purely on the basis of meeting the objectives of the physical and economic criteria should not normally be recommended unless it receives local support. A project which meets the objective criteria and which is strongly supported by the project beneficiaries should, ordinarily, receive a recommendation for highest priority of development.

State Rights — D. Sometimes due to rights of states or other political entities to develop water, power, or other resources, the priority of development must be adjusted with the development proposed by the state. This is especially pertinent where interstate compacts exist.

Commitments — E. Commitments to project sponsors or Congressional or Presidential requests, may affect the priority of investigations or development of projects. Ordinarily, commitments should not be made except to recognize proposals or recommendations mutually satisfactory to all principal interests, and then only to the extent of agreement to recommend the decisions to higher authority. If a commitment based on preliminary findings is made, and it is later found by more detailed surveys to be impractical or impossible of execution because of physical or economic conditions, then such commitment should be retracted and all parties notified of the facts supporting the retraction. Project authorization and appropriation of construction funds do not in themselves constitute a mandate to construct a project, or any separable part thereof, which later studies show to be physically or economically unsound.

Other Factors — F. Lesser criteria, organizational in nature, may enter into project selection for investigation programs. These involve availability of funds, character of available personnel, and requirements for carrying out the work in an orderly manner, etc. Particular attention should be given to programing the collection of physical data requiring several years of record.

.1 Planning reports are classified into six general categories: TYPES OF REPORTS

A. Basin, subbasin, and project reports, which cover potential developments and may relate to an entire river basin, to a subbasin or area, or to specific developments.

B. Definite plan reports, which relate only to authorized projects and divisions or units of projects not yet constructed, or only partially constructed.

C. Reconnaissance reports, which are concerned only with the preliminary analysis of potential developments.

D. Rehabilitation and financial adjustment reports, which are concerned with the analysis of operating Bureau projects.

E. Power planning and marketing reports, which are related to the development and utilization of electrical energy from potential or existing multiple-purpose projects.

F. Special-purpose reports, which relate to special planning problems or other requirements.

.2 Each of the above types of report has a specific purpose and use, defined as follows: PURPOSE & USE

A. Basin, subbasin, and project reports present the findings and conclusions of an investigation which has been made to determine: (1) the economic and engineering feasibility or infeasibility of the overall plan for the development of the land, water, power, and related resources of the basin or project area; and (2) the relationship of such development to the area, the region, and the Nation. The primary uses of these reports are to provide information for internal use within the Bureau and Department in accordance with Reclamation Laws and for the affected states, Federal agencies, and others, in accordance with the Flood Control Act of 1944 and the Act of August 14, 1946 (60 Stat. 1080); and where desirable to serve as the basic document for securing project authorization. Unless specifically excepted, a project report will be restricted to consideration of a single, closely integrated area, which is potentially susceptible of separate construction and development. In contrast, a basin or subbasin report will present for approval an integrated plan for the development of the land, power, and water resources in the basin. This will involve existing projects, projects recommended for authorization and construction, and projects to be considered for authorization at a later date. (See Chapter 4.2.) BASIN, SUB-BASIN, & PROJECT REPORTS

B. A definite plan report presents the findings and conclusions of such further investigations as are necessary to determine the detailed plan of development for a project, division, or unit of a project. Also, it includes the design data needed for preparation of plans and specifications as called for in Volume IX. These can usually be completed during the period between authorization and construction. These reports are used primarily by the Commissioner, the Regional Directors, and their respective staffs as the basic control for the proper and orderly development of the land, water, power, and related resources of the project area. (See Chapter 4.3.) DEFINITE PLAN REPORTS

C. A reconnaissance report presents, on the basis of office study of existing data and a minimum of reconnaissance field surveys, information on the potentialities of land and water resource development in a given area. Its main purpose and use is to indicate whether further detailed investigations are justified and, if so, their scope. Reconnaissance reports also serve as background material in formulating comprehensive basin plans. (See Chapter 4.4.) RECONNAIS-SANCE REPORTS

REHABILITATION & FINANCIAL ADJUSTMENT REPORTS

D. In some cases, reports of surveys for rehabilitation of existing project systems, and reports of project conditions calling for financial adjustments include recommendations for minor changes in the project plan. In the majority of such reports, however, no changes in plan are contemplated and the reports serve as bases for work programs and amendatory repayment contracts.

POWER PLANNING & MARKETING REPORTS

E. Power planning reports are reports dealing with the development of power features of a basin, an area, a proposed project, or a supplement of an existing project. They cover hydroelectric generating plant, standby or peaking facilities, a transmission line or system, or both. They concern the optimum development of power and utilization of same consistent with prior uses of water in conjunction and coordination with other power plants and power systems. Power market reports deal with the marketing and sale of power and concern, primarily, the determination of present and estimates of future power markets. As such, they concern power market data on which are based marketing and sales determinations such as volume and rate schedules. (See Chapter 4.6 and Volume VI for further details.)

SPECIAL-PURPOSE REPORTS

F. Special-purpose reports present the findings and conclusions of special investigations and studies which are required to satisfy specific requests or legislation, to meet critical problems associated with only one phase of the development of projects under investigation, or to provide information on specific phases that will be applicable to more than one development. (See Chapter 4.7.)

RESPONSIBILITY FOR PREPARATION

.3 The Regional Director, within his responsibility for the development and execution of integrated regional irrigation, land-use, and power programs, is responsible for the preparation of all planning reports within his region. During the preparation of the report he is responsible for cooperative work and the coordination of plans with other agencies or political subdivisions, to the maximum possible extent that can be accomplished at the regional level, through the field offices of other Federal agencies, and through the officials of states and other political subdivisions. The planning report generally is prepared in preliminary draft form in the district, area, project, or investigations office under the technical guidance and supervision of the Regional Planning Engineer, the Regional Operation and Maintenance Supervisor, or the Regional Power Manager, in accordance with the branch having the primary responsibility for the work. When completed in preliminary draft form, it is submitted by the preparing office to the Regional Director for such modification as may be necessary at the regional office level, approval, and further processing in accordance with Chapter 4.9.

OBJECTIVES OF THE REPORTS

.4 Reports should be comprehensive, readable, and understandable, and should present objectively the findings and conclusions of the investigations. It should be borne in mind always that a report as prepared in the area or field office constitutes a permanent record of the Bureau's activities, that it is the basis for long-range development which must be predicated on a sound foundation, that it may be presented for Departmental, interagency, committee, state, Presidential, or Congressional action, and finally, that the efficiency and quality of the Bureau's operations are judged largely by the reports which it makes available to the Congress and to the public. (See Chapter 4.8 regarding unfavorable reports.) In order to attain these objectives, the form and scope of reports, the processing procedure, and the editorial techniques used shall conform to Chapters 4.2 to 4.10, inclusive. Details pertaining to the reproduction of reports are given in Volume XXI, and to editorial and stenographic techniques in Volume XXII.

.1 Basin, subbasin, and project reports are submitted to the Commissioner for further action, including approval and submission to the Secretary and to the Congress: TYPES

A. A basin or subbasin report is prepared to present a comprehensive plan for the orderly development and conservation of the water and related resources of an entire river basin or major tributary area. These reports are sponsored by and prepared under the general supervision of the Bureau of Reclamation and present the plan of development on a Departmental basis, incorporating into the plan the pertinent interests of the various agencies in the Department of the Interior. Basin reports include appropriate consideration of the interests and plans for development by other Federal, State, and local agencies. The report presents, in addition to a comprehensive basin plan, a selection of the project or projects which are most urgently needed and which should be recommended for construction as the initial or next stage of development. The economic justification of the comprehensive basin plan is based on the comparison of annual benefits and annual costs resulting from development of the entire basin plan. Unless previously approved otherwise by the Commissioner, each favorable basin or subbasin report shall include a recommendation for Congressional approval of the comprehensive basin plan, and a recommendation for authorization of the works included in the next stage of development. These reports shall present sufficient descriptive and economic information to permit a clear appraisal of the comprehensive plan, and a clear understanding of the urgency of the recommended initial or next stage of development. BASIN & SUBBASIN REPORTS

B. A project report is prepared to present a plan of development for an individual new project, new division of a project, or new supplemental works on a project, an analysis of the economic feasibility of the project and the desirability of undertaking construction of the project works. The report shows how the individual project fits into the basin plan if one has been developed or how it would fit into a desirable basin-wide scheme if a basin plan has not been reported. The report should present all facts essential to the authorization of a project including the essential interests and reports of other Department of the Interior agencies. PROJECT REPORTS

.2 Each basin and project report should present a clear picture of the physical features and existing development of the subject area and must include appropriate consideration of the following factors: ESSENTIAL ITEMS

A. Development plans.

B. Engineering feasibility.

C. Benefits and costs.

D. Financial feasibility and probable repayment.

E. Desirability and urgency of need for proposed work.

F. Proposed general order of construction.

.3 Basin, subbasin, and project reports as submitted to the Commissioner shall consist of the signed Report of the Regional Director, and a substantiating report which shall include pertinent reports of all other interested agencies of the Department of the Interior. In addition, appendixes (see Paragraph 4.2.11) covering each major phase of the investigation shall be prepared in the regional, district, area, project, or investigations offices for use as required in supplementing the report and as a basis for further investigations or for design and construction. A limited number of copies of certain appendixes shall be sent to the Commissioner's office as indicated in Chapter 4.9 FORM & CONTENT OF REPORT

REPORT OF THE REGIONAL DIRECTOR

.4 The Report of the Regional Director shall be complete in itself and should be concise and informative to the nontechnical reader as well as to the technician. Primarily it should consist of statements of fact and conclusions with reliance upon the substantiating report for proof or justification. In this respect it should comprise as brief an abstract of the substantiating report as possible and should avoid all unnecessary duplication. The Report of the Regional Director will amend the substantiating report to the extent necessary to reflect the combined views of the branches of the Bureau, and of other agencies and interests. It is expected that there may be minor differences between the Report of the Regional Director and the substantiating report. It is desired that the Report of the Regional Director should not indicate views directly opposed to those stated in the substantiating reports, although it is realized that this condition may occur in regard to some controversial issue. In such case a formula that is mutually agreeable to the agency involved and to the Bureau may be given in the Report of the Regional Director for the settlement of the problem. The agencies concerned will have an opportunity to check this formula when the report is reviewed by Departmental or interagency committees.

See Adv. Sup 3

CONTENT OF REPORT OF THE REGIONAL DIRECTOR

.5 The outline presented below may be used as a general guide in the preparation of the Report of the Regional Director. Selection and arrangement of the subjects to be included and the scope of the treatment of any individual subject will be within the Regional Director's discretion and will vary for basin, subbasin, and project reports and with the relative size of the comprehensive plan or individual projects. In many instances a single sentence or brief paragraph will suffice to cover an item. Tabulations should be held to a minimum. Across the top of each page of the report shall appear the words--"Report of the Regional Director."

REPORT OF THE REGIONAL DIRECTOR

A. Letter Heading. The Report of the Regional Director shall be in the form of a letter to the Commissioner. The subject of the letter should contain the word "report;" as "Report on Comprehensive Plan of Water Resources Development--Black River Basin."

B. Introduction.

(1) Authority. When applicable, the following language shall be used in citing the authority for making and transmitting a report: "This report is authorized to be made by virtue of the Federal reclamation laws (Act of June 17, 1902, 32 Stat. 338 and acts amendatory thereof or supplementary thereto)." Other applicable laws, such as the Boulder Canyon Project Act or Adjustment Act or the Flood Control Act of 1944, should be added or substituted where appropriate.

(2) Cooperation and Acknowledgements. Full recognition should be given here to all contributions and cooperation extended by Federal, state, and local agencies.

C. General Description.

(1) Physical Features. Brief picture of physical features.

(2) Climate. Mean annual temperature and precipitation, growing season precipitation, frost-free period, growing season, etc.

(3) History and Settlement. Brief history, population, important towns.

(4) Industry. Agriculture, other main industries, transportation facilities and markets.

(5) Economic Conditions. Community development, standard of living.

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A UNITED STATES
DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Washington 25, D. C.

Approved: May 8, 1953 Effective: Upon receipt Received:	RECLAMATION MANUAL	VOLUME III BASIN AND PROJECT DEVELOPMENT ADVANCE SUPP. 3

Part 4, Planning Reports, Chapter 4.2 Basin, Subbasin, and Project Reports, Paragraphs 4.2.4 and 4.2.5, Report of the Regional Director

A copy of the attached October 9, 1952, directive from the Chief of Engineers to Division Engineers was transmitted to the Assistant Commissioner of Reclamation by memorandum of April 29, 1953, from the Secretary of the Interior.

The directive calls for inclusion in the project planning reports of the District Engineers the substance of the views of the Fish and Wildlife Service on proposed projects. It also required that the reporting offices take a positive position on each of the recommendations of the Fish and Wildlife Service report.

The Secretary's April 29 memorandum requests that similar procedures be adopted in the case of planning reports of the Bureau of Reclamation. The Secretary recognizes that these procedures are now being followed in certain instances by some of the Regional Directors, but points out that the practice is not a uniform one.

The requirements contained in Subparagraphs 4.2.5H and 4.2.5J are, therefore, supplemented by the following instructions at the request of the Secretary:

(1) The substance of the report of the Fish and Wildlife Service shall be incorporated in the Report of the Regional Director.

(2) The Regional Director in his report shall make every effort to reconcile any differences in opinion between the two agencies at the field level. If these differences cannot be reconciled, they shall be referred to the Commissioner, attention 700, for coordination, if possible, at the Washington level.

These instructions will be incorporated in future revisions of Chapter 4.2 of this volume and as may be necessary, in pertinent chapters of Volumes IV and VII.

Fred G. Aandahl
Assistant Secretary - Water and Power

Attachment

Distribution: III

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Y

DEPARTMENT OF THE ARMY
OFFICE OF THE CHIEF OF ENGINEERS
Washington 25, D. C.

ENGWD 800.92 9 October 1952

Subject: Cooperation of Fish and Wildlife Service, Department of Interior, in Preparation of Flood Control and Navigation Preliminary Examination and Survey Reports

TO: Division Engineers, except Division Engineers, EOD and MD

1. The Fish and Wildlife Service of the Department of Interior has raised questions concerning the transmission of its views on projects recommended or discussed in preliminary examinations and survey reports of the Corps of Engineers to Congress and to interested agencies. The Service desires that its views be presented to Congress for its consideration in acting upon proposed projects and that the position of the Corps of Engineers with respect to these views be clearly stated. This objective is not necessarily met by inclusion of the report of the Fish and Wildlife Service as an appendix to the Corps of Engineers' report since appendices are normally not printed.

2. In following the spirit of the Federal Inter-Agency River Basin Committee agreements, as well as the intent of Orders and Regulations, District Engineers will make certain that the substance of the Fish and Wildlife Service views on proposed projects are contained in the body of the preliminary examination and survey reports, and that the comments of the reporting officers on these views are also included. Every effort should be made to reconcile differences in opinion between the two agencies at field level. If these differences cannot be reconciled, they should be referred to the Chief of Engineers for coordination, if possible, at this level prior to completion of the report.

BY ORDER OF THE CHIEF OF ENGINEERS:

A. C. WELLING
Colonel, Corps of Engineers
Executive

REPORT OF THE REGIONAL DIRECTOR (Continued)

CONTENT OF REPORT OF THE REGIONAL DIRECTOR (Cont.)

(6) Water Supply. Surface and groundwater supplies of the area.

(7) Land. Arable lands, location, soils, topography, drainage, classification.

(8) Other Natural Resources. Forests, minerals, fish and wildlife, etc.

D. Present Development of Land and Water Uses.

(1) Land Use. General land uses such as dry farming, irrigation, forests, grazing, and waste. Agricultural products.

(2) Irrigation. Description of irrigated areas, important organizations, and major works within the area.

(3) Other Uses. Power, municipal and domestic water supply, fish and wildlife propagation, recreation, flood control, sediment control, navigation, salinity control, and pollution abatement.

(4) Transbasin Diversions. Brief descriptions of any projects diverting water from or to the basin.

E. Problems of the Area.

(1) Land and Water Use. Land and water use problems of the basin or project area including water shortages, compact requirements and administration of water.

(2) Power. Deficiencies in power supply.

(3) Flood Control. Past and potential floods and flood damages.

(4) Other. Municipal and domestic water supply, recreation, sedimentation control, ★housing and community facilities requirements for construction, operation, and maintenance at remote locations, etc.★

F. Potential Developments. Include not only the elements of the proposed plan for ultimate development of the basin but discuss other developments desired by local interests which as a result of this investigation have been found to be less feasible, undesirable, or otherwise not utilized. List the essential project works, and if practicable, describe the major features briefly.

(1) Irrigable Areas. Brief description of soils and of land classification for each area.

(2) Water Requirements. Unit diversion requirements, taking into account the use of return flows.

(3) Water Supply. Adequacy of supply as to quantity and quality, with project constructed according to recommended plan.

(4) Water Rights. Important rights affecting potential developments and modifications required to insure a project water right.

(5) Power. Potential markets, load demands, production, and distribution under recommended plan of development.

(6) Flood Control. Include discussion of authorized improvements not yet constructed.

(7) Comprehensive Plan of Development. Brief description of plan including listing of projects together with costs, and the preferred order of development.

CONTENT OF REPORT OF THE REGIONAL DIRECTOR (Cont.)

REPORT OF THE REGIONAL DIRECTOR (Continued)

(8) Initial or Next Stage. The project or projects recommended for early construction. General order of construction of features by years and estimates of annual appropriations necessary to permit efficient construction.

(9) Engineering Feasibility. Include statement that works proposed for authorization have engineering feasibility.

(10) Alternate Plan. Discuss any alternates to the proposed ultimate plan of development.

G. Economic Analysis. For the comprehensive basin plan a general presentation of the related economic analysis showing summary totals for estimated benefits, costs, and repayment is sufficient. For projects recommended for authorization, a more detailed and explicit presentation on economic feasibility is desirable.

(1) Benefits. Benefits of the recommended plans of development including discussion of intangible benefits. (See Volume XIII for method of computation.) State the basis used for estimating crop prices.

(2) Costs. Itemized costs of the major features including both capital and annual costs. (See Volume XIII.) Construction cost estimates shall be based upon current prices. State the cost index used to bring construction cost estimates prepared on any other basis to the current price basis. If a long construction period is contemplated a separate cost estimate based on future expected cost indexes as provided by the Chief Engineer may be included. ★(Completed Form PF-1, "Official Estimate of Total Project Cost," must be included. See Volume XXIII.)★

(3) Benefit-cost Ratio. State both the overall benefit-cost ratio and the farm return-farm cost ratio. (See Volume XIII.)

(4) Allocation of Costs. Allocation of costs to the various functions provided for in the project or basin plan. (For a basin-plan limit cost allocation to basin-wide application.) (See Volume XIV.)

(5) Reimbursement. Probable repayment by water users and revenues from the sale of water and disposal of power by separate projects if feasible. Show also nonreimbursable items. (See Volumes VI and XV.)

H. Related Investigations. Summarize the pertinent findings of the related reports of other agencies of the Department, by other Federal agencies, or by states and other parties. Discuss any continuing or further investigations which should be made by such agencies.

I. Conclusions. Brief summary of conclusions.

J. Recommendations. The recommendations contained in the Regional Director's basin and project reports should be specific so that, when a project is authorized by the Secretary in accordance with Section 9(a) of the Reclamation Project Act of 1939, or when a bill authorizing the plan or project as described in the report is enacted, it will be clear as to what is to be authorized, who is to build the units of the plan or projects, who will operate and maintain them, what laws apply, how or upon what basis the costs shall be allocated, and who will repay the reimbursable costs. Any desired provisions not covered by existing law should be in the form of a specific recommendation.

.6 As stated in Paragraph 4.2.5 the selection of subjects from the outline therein will vary for different basin, subbasin, and project reports. The outline presented in Paragraph 4.2.5 is slanted primarily at basin reports although readily adaptable to project reports as well. In relation to project reports, a more detailed discussion of the plan set forth including descriptions of such items as major features, relocation, and land leveling may be desirable. A new section should be added, presenting a full discussion of how the project will fit into the comprehensive basin-wide development.

ALTERNATE OUTLINES FOR REPORT OF THE REGIONAL DIRECTOR

.7 The substantiating report, which will be bound with the Report of the Regional Director and will accompany that report when it is submitted to the Congress, should present, in chapter form, discussions of the subjects necessary to a thorough understanding of the findings, conclusions, and recommendations in the Report of the Regional Director. These chapters of the substantiating report shall be in sufficient detail to substantiate, for the technical reader, the facts and conclusions contained in the Report of the Regional Director. The substantiating report shall present not only the results of the investigation but also the bases of analyses and computations and reference to methods used.

SUBSTANTIATING REPORT

.8 The substantiating report covering a basin, subbasin, or major project should be essentially a complete report, exclusive of recommendations. However, in the case of a report on a minor subbasin or a report on a relatively simple project, where the need for substantiating material is not great, the Report of the Regional Director may be expanded to include the data normally presented in the substantiating report.

OMISSION OF SUBSTANTIATING REPORT

.9 The subjects in the following list, by subparagraph and title, are intended to serve as a check list for the report writer in his consideration of those subjects which should be included in a substantiating report, but are not to be considered as excluding other subjects necessary in a particular interest or as indicating any standard order of presentation:

SUBJECTS TO BE CONSIDERED IN THE SUBSTANTIATING REPORT

A. General description

B. Potential development

C. Designs and estimates

D. Water supply

E. Project lands

F. Agricultural economy

G. Power

H. Flood control

I. Sediment control

J. Drainage

K. Municipal, domestic and industrial water supplies

L. Fish and wildlife conservation

M. Recreation

N. Stream pollution abatement

O. Navigation

SUBJECTS TO BE CONSIDERED IN THE SUBSTANTIATING REPORT (Cont.)

P. Financial analysis

Q. Alternative plans

The make-up and balance of individual reports vary so widely that it must be within the discretion of the Regional Director to select his own pattern. It may be desirable to discuss certain subjects such as physical geography or water supply on a basin-wide basis or it may be desirable to divide a basin into physical areas and discuss each area separately. Power and navigation which may receive prominent attention in one basin, may be of relative insignificance in another. The scope of treatment of any given subject will vary with the need.

GENERAL DESCRIPTION

A. The first chapter of the substantiating report, entitled General Description, should present a good background description of physical characteristics, basin settlement, industrial development, general economy of the region, and a summary of other agency investigations.

(1) Physical Geography.

(a) Location. The general geographic location of the project. Explain project name significance.

(b) Physical Features. Physical features or characteristics of the project area and vicinity.

(c) Climate. General climatic conditions and summaries of climatic statistics, including temperature, precipitation, and frost data.

(d) Geologic Conditions. A brief geologic history of the general region.

(2) Settlement.

(a) History. A brief summary of the history of the settlement of the basin or project area and vicinity. This topic need not be discussed in extended detail, but it is useful in presenting the background for the proposed development, especially as it relates to irrigation practice, failures of systems, etc.

(b) Population. Data on the present population in the basin or in the project and the surrounding area, and a discussion of the population trends and growth.

(3) Industrial Development.

(a) Local Industry. A description of the general industrial development in the basin or project area and vicinity.

(b) Transportation and Other Facilities. The local transportation system and the utilities such as telephones, power, etc.

(c) Land Uses. The general land uses in the region and presentation of a general description of the type of local agricultural development.

(d) Irrigation. Local irrigation developments and a general description of other irrigation developments, the water supply of which would be affected by project development. If such developments are numerous the data should be tabulated and necessary information given in footnotes.

(e) Other Water Uses. A general description of other local water uses, such as hydroelectric power and municipal water supply. Serious local water problems, such as flood hazards. If such developments

are numerous the data should be tabulated with necessary explanations given in footnotes.

GENERAL DESCRIPTION (Cont.)

(f) Undeveloped Resources. A general discussion of the undeveloped natural resources of the project area and vicinity, such as timber and minerals. Water supply, irrigable lands, reservoir sites, and power sites should be mentioned, but the detailed discussions of these features will be included in other discussions.

(4) Economic Conditions.

(a) General Conditions. A general description of the overall economic conditions.

(b) Relief Problems. The existing public relief problems, past public relief problems which may recur in the future, and other local employment problems.

(c) Community Needs. The need for irrigation, flood control, and potential developments of natural resources.

(5) Investigations and Reports.

(a) Previous Investigations. All previous studies and reports which are related to the potential basin plan or project. The title of the report, the reporting or sponsoring agency, and the date of the report should be correctly stated. A summarization of the contents as they may affect the planning of the project should be included.

(b) History of Investigation. Brief discussion of the history of the present investigation, setting forth the original sponsorship and the authorization of the investigation.

(c) Scope of Present Investigations. Discuss the investigations and studies made during the planning of the project or plan being reported.

(d) Acknowledgments. A short, general discussion of aid and assistance received from Federal, State, county, local agencies, and individuals in the conduct of the studies and investigations. All contributing agencies should be mentioned by name and, in addition, certain individuals as may be desirable.

B. The elements of the comprehensive basin plan (or project plan) should be presented in summarized or tabular form together with a discussion of alternate plans which may have been investigated or which may be desired by others. In the case of a basin or subbasin report this chapter should include a discussion of the proposed initial development under the comprehensive plan.

POTENTIAL DEVELOPMENT

C. The chapter on designs and estimates should be a discussion of the estimates, problems of designs, and the estimates of cost. The degree of detail will vary with the report, less detailed presentation being possible for a basin plan report as compared to a project report. In a major basin report, discussion of many of the following subjects may be limited to works included in the proposed initial development. (See Volume X.) Estimates of cost should be broken down in conformity with appropriate items in the uniform accounting system of the Bureau. (See Volume XXIII.) Subjects for consideration are:

DESIGNS & ESTIMATES

(1) Geology.

(a) Site Geology. Detailed discussions of the specific geologic conditions at the damsites of projects recommended for authorization. The discussions should cover fully the descriptions of the particular

DESIGNS & ESTIMATES (Cont.)

geologic conditions found and how they will affect project design and construction.

(b) Foundation Explorations. Describe the explorations made to determine the geologic conditions at the site of potential foundations and abutments. Descriptions and illustrations of the conditions encountered should be included.

(c) Construction Materials. A geologic discussion of the construction materials available, including their sources, quality, quantity, suitability, etc., supported by the results of laboratory tests. Materials to be excavated should be similarly described.

(d) Conclusions and Recommendations. A summary of the geologist's conclusions as to the suitability of the sites for the potential developments. It should be accompanied by the geologist's recommendations for specific action required for treatment of special or unusual geologic conditions.

(2) Design and Construction Problems.

(a) Accessibility. General accessibility of sites of potential major structures to existing transportation systems and other facilities. ★★★

(b) Rights of way. Unusual or difficult problems involved in the acquisition of rights of way.

(c) Design Floods. Studies of potential flood flows and volumes as used for spillway designs for dams, and flood-routing studies for reservoirs. (See Volume IV.)

(d) Construction Period. A discussion of the proposed period of development of the units of the comprehensive basin plan, or period of construction of the project works in the case of a project report.

★(e) Housing and Community Facilities. Housing requirements at remote locations, including a discussion of the number, type, and kind of housing facilities needed based on anticipated personnel requirements for construction and operation and maintenance. Estimates of costs, preliminary layout and location of Government housing, and probable rental returns and salvage value should be included. ★

(f) Special Problems. Discuss special problems peculiar to the project.

(3) Project Works. Discuss each of the project works planned for construction. Include descriptions of the design, and estimate sheet showing construction quantities and costs, and preliminary design drawings (general layout or plan and section) for major structures. These discussions can be presented as follows:

(a) Storage. Describe the dams and reservoirs, including the right of way and the relocation of roads and other public facilities.

(b) Irrigation Distribution Works. Describe the main canal, lateral system, drainage system, and other irrigation works.

(c) Other Features. Discuss other features, such as power or flood-control works.

(d) Anticipated Operation. In order to minimize the chances of later confusion, and to improve understanding of the purposes for which reservoirs contemplated in the report shall be used, especially where an allocation of space to flood control or navigation will be made for which the Secretary of the Army is empowered to prescribe operating regulations, the principles and purposes which will govern the operation of each reservoir together with the contemplated method of reservoir operation shall be set forth.

(4) Cost Estimates. DESIGNS & ESTIMATES (Cont.)

(a) Construction. Summarize the total estimated costs of construction, including the costs of investigations and surveys, operation and maintenance during construction, and the purchase of rights of way, acquisition of existing works or water rights where required, and purchase of operating equipment. These estimates ★are shown on Form PF-1 and★ should be on a price basis in accordance with the latest prevailing instructions. (See Volume XXIII in regard to the uniform accounting system of the Bureau.)

(b) Operation and Maintenance. Show the total estimated annual costs of operation and maintenance for all project works, including the general costs, repairs and replacements, and the costs of special items, such as purchase of electric energy for pumping.

D. The chapter on water supply should present the studies of the available surface and ground-water supply and its utilization. (See Volume IV.) The following subjects should be given consideration: WATER SUPPLY

(1) Water Resources.

(a) Available Supply. Discussion of the available water supply, giving source, the runoff records (or ground-water data) and estimates of streamflow when needed, including a description of the methods and computations used in extending the records to make the estimates.

(b) Quality of water. Discuss the quality of the water, giving a summarization of the analyses determining the dissolved solids and the percent sodium when such analyses are necessary. Discuss the suitability of the water supply, including return flow, for irrigation and other uses.

(2) Water Requirements.

(a) Consumptive Use and Farm Delivery Requirement. The derivation of net irrigation water requirement or consumptive use which, unless better information is available, is to be derived by the Lowry-Johnson method (Transactions of ASCE Vol. 107--1942--P 1243). Emphasis should be put on farm delivery requirements as these can be compared with local experience.

(b) Diversion Requirements. The diversion requirements for irrigation, giving full consideration to transit and operation wastes, deep percolation losses, leaching, and stream depletion or accretion.

(c) Return Flow. The probable yields and potential utilization of return flow where the re-use of these flows is contemplated, either on the project area or downstream.

(d) Evaporation Losses. The determination of the evaporation losses of water in reservoirs, or in transit, where this loss would be material.

(e) Sedimentation. The determination of storage space required to accumulate sediment in the reservoir during the repayment period or longer if justified, the effect on downstream channels or reservoirs of sediment storage, and the effect of sediment on the ultimate existence of the project.

(f) Special Uses. When applicable, the requirements for municipal, domestic, industrial, or other special uses can be discussed although, if preferred, these may be discussed in other appropriate chapters on the various uses and only a summary presented in this chapter.

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WATER SUPPLY (Cont.)

(3) Water Rights.

(a) Existing and Potential Rights. Describe and summarize the existing and potential rights in the basin or both upstream and downstream from the project.

(b) Project Rights. The effect of nonproject rights on the project supply; the rights initiated for the projects; rights needed for the development of the projects, including plans for purchasing, pooling, and substitution; existing litigation which may effect projects rights; and the applicability of existing or proposed interstate compacts.

(4) Water Utilization.

(a) Operation Studies. Discussion of the operation studies made to determine the adequacy of the basin or project water supply, storage facilities, and related features, and the coordination and relative superiority of uses. Summarize the results of the studies in appropriate tables and charts, accompanied by complete explanation of methods used.

(b) Possible Water Shortages. Give a discussion of the probable water shortages that may occur.

PROJECT LANDS

E. The introductory paragraphs on lands shall present general information on the location, size and conformation of the lands under investigation. The lands within the project boundaries, both irrigable and nonirrigable, shall be described with the emphasis on those which are considered irrigable. (See Volume V.)

(1) Soils. The soils of the project area should be discussed with respect to their geologic origin, physiographic position and factors concerned with their development. Their principal profile, textural, permeability and fertility characteristics also should be discussed and related to the native vegetation and adapted crops. If a soil survey of the area has been made, the characteristics of the principal soil series and types should be described.

(2) Topography. The salient topographic features of the project area, such as elevation, slope, and surface relief should be considered from the standpoint of accessibility to and distribution of irrigation water and from the standpoint of correcting inherent deficiencies due to an uneven surface. The cost of such correction or development, and its effect on the soil must be considered.

(3) Drainage. Existing and anticipated surface or subsurface drainage conditions should be described. Any specific problem and measures for its correction should be analyzed in the same general manner as surface relief problems. In the analysis it will be necessary to consider gradient, depth to impervious material, the permeability of the soil and its susceptibility to leaching. If drains are to provide for removal of storm waters, that phase of the problem should be presented.

(4) Special Problems. Special probelms associated with or likely to arise in the project area, such as the presence of selenium or excessive salinity or alkalinity, should be treated separately with respect to their extent, limitations, and remedial measures. With respect to salinity-alkalinity, the types and permissible amounts, the source, and areas affected and the treatment should be given adequate differential consideration.

PROJECT LANDS (Cont.)

(5) Land Classification. This section should provide a brief but comprehensive treatment of the scope, principles and objectives of the land classification. This will require description of the type of survey employed, the economic, physical, and engineering factors involved and the steps followed in attaining the ultimate objective of establishing the irrigable area.

(a) Arable Lands. The project specifications for the arable land classification shall be shown, and the methods used in mapping, making soil borings, and testing the soils shall be described briefly. The results shall be presented as general discussions of the characteristics, productivity, use limitations, and extent of each land class recognized in the survey and the more significant subclasses.

(b) Irrigable Lands. The determination of the irrigable lands shall be described including justification for the elimination of any arable areas. Only net irrigable acreages (gross irrigable less allowance for right-of-way, farmsteads, and similar nonproductive uses) shall be reported. These acreages should be by classes and subclasses for the project and for any recognized subareas or divisions. A general land classification map shall show the gross irrigable area by classes.

AGRICULTURAL ECONOMY

F. The chapter on agricultural economy should present detailed information on the agricultural economy of the project area, both for the present or "without" and the anticipated or "with" conditions, including effect of anticipated water shortages. This information should be properly related to that presented on the overall economy in the chapter on General Description as well as to the treatment of the irrigation repayment and related analyses. (See Volumes III, V, and XV.)

(1) Present. The intensity of and the detail in the analysis of the present economy, i.e. the size and type of farm and the organization of the various enterprises, will depend in a large measure on the extent of the present development which may range from raw or grazing land to partially developed irrigated land. Whenever significant differences in land use and income per acre are associated with quality of land, the analysis and presentation should be on the basis of land classes as outlined in Part 2 of Volume V. Specific consideration should be given to:

(a) Fiscal Aspects. A brief but comprehensive analyses of the local governmental structure including the rural tax base and rates and current fiscal conditions; land values; the farm mortgage and farm credit situation; and tenure, including both ownership and operating patterns.

(b) Crops and Livestock. The development, analyses, and presentation of the various crop and livestock enterprises including such factors as distribution, production, value, and labor requirements, and the integration and budget analysis of the enterprises for representative farms.

(2) Anticipated. A comprehensive picture of the anticipated agricultural economy under the proposed development should be presented. In general, it should follow the presentation for the present economy as set forth above. In developing and analyzing the anticipated economy, adequate consideration should be given to conditions on comparable developed projects, to the Bureau objectives and to the requirements or limitations of the project under investigation. In addition, consideration should be given to the following problems associated with the changes in land use resulting from, and the organization necessary for, irrigation:

AGRICULTURAL ECONOMY (Cont.)

(a) Farm Development. Buildings, land preparation, and the farm distribution and drainage system.

(b) Farm Settlement. Size of unit and new opportunities for settlement, excess land holdings, and antispeculation.

(c) Development Period. Length and justification thereof.

(d) Local Support. Attitude of land owners and local interests toward the proposed project and their willingness to organize an irrigation district and to complete a repayment contract.

(3) Irrigation Repayment. A comprehensive and objective analysis of the potential irrigation repayment shall be presented. This should include an analysis and summary of the amortization capacity by land classes together with a discussion of the results from the check methods which were used, justification for any deviation from the amortization capacity which may be involved in the recommended annual installment, establishment of the recommended repayment obligation, and recommendations pertaining to types of contract, variable payment plans and district organization.

POWER

G. The chapter dealing with the power-development features of the project should discuss the power-production potentialities, the power market, and the value of the power which could be produced. (See Volumes IV and VI.)

(1) Present Development. A general description of the existing power facilities, including the generating capacity, output, transmission system, and their ability to meet present demands. Tabulations may often be used to advantage in presenting these data.

(2) Power Market. Discuss the existing market, the growth trends, and the anticipated market, giving due consideration to other potential power developments in the region.

(3) Potential Development. Describe the development planned. Include discussions with reason for the selection of generating capacities; the anticipated power production; the transmission of electric energy; and the sequence and timing of construction of the various project power units.

(4) Power Revenue. Present a financial study showing estimated annual expenditures and returns throughout the amortization period. Include a discussion of the average rate for firm power necessary to achieve project payout within the adopted period.

FLOOD CONTROL

H. This chapter should include the flood history of the basin or project streams and area; damages which have occurred and that may occur; the extent to which such damages can be prevented by the project works; and the flood-control benefits which would result from the project. Essential cooperation with the Corps of Engineers, Army Department, and local flood-protection districts should be discussed. (See Part 6 of Volume IV and Part 2 of Volume VII.) The following topics might be considered:

(1) Historical Floods. The peak and volume, frequency, extent, and resulting damages of the historical floods.

(2) Potential Floods. The probable flood peaks, volumes, and frequencies that can be anticipated.

(3) Regulation and Benefits. Discuss the flood-control regulation that can be provided by the project and the evaluation of the benefits that will be derived therefrom through the prevention or reduction of flood damages.

I. This chapter should present a discussion of the silt and debris problems of the project, the possibilities of providing control, and the evaluation of benefits. (See Part 9 of Volume VII.) The discussions might be subdivided as follows: SEDIMENT CONTROL

(1) Problems. The general silt problems involved in the basin or project and describe any existing control works.

(2) Data. Discuss all available data on the rate of siltation, the manner in which the silt and debris is deposited, and the general conditions which have affected the deposits in the past and which will affect them in the future.

(3) Damages. The damages under present conditions and those estimated for the future.

(4) Potential Control. The possibilities and plans for providing silt and debris control as a part of the project development.

(5) Evaluation of Benefits. The evaluation of the silt and debris control benefits that would result from the potential development.

J. This chapter should include discussions of drainage problems and remedies where a portion of the development is solely a drainage development; where an exceptionally large drainage development is involved; or where the drainage problems are unusual or complex, requiring elaborations on or additions to the discussions of drainage features generally included under the discussion of the project lands in Paragraph 4.2.9E(3). The discussions should cover the following topics: DRAINAGE

(1) General Drainage Conditions. The general conditions affecting the drainage of project lands and any existing drainage works. Generally, a rather detailed discussion of both surface runoff and groundwater conditions is necessary.

(2) Special Problems. The particular drainage problems of the area.

K. The chapter on municipal, domestic, and industrial water supplies should present a discussion of the problems and plans involved in supplying municipal and domestic water, with consideration of utilization of both surface water and groundwater when applicable. (See Part 4 of Volume IV and Part 3 of Volume VII.) The presentation can be covered as follows: MUNICIPAL, DOMESTIC, & INDUSTRIAL WATER SUPPLIES

(1) Present Development. The existing facilities, uses, and the population served.

(2) Anticipated Needs. The population growth trends and the anticipated future demands for water.

(3) Water Requirements. The derivation of the water requirements, including the distribution system losses, and, when applicable, special industrial and commercial uses.

(4) Special Water Treatment. The particular water treatments that would be required to utilize the project water for municipal, domestic, or special industrial uses.

(5) Potential Development. The possibilities and plans for the use of project waters for a municipal and domestic supply.

(6) Charges and Benefits. The permissible water charges and the evaluation of the benefits of providing municipal and domestic water as a part of the project.

FISH & WILDLIFE CONSERVATION

L. This chapter should discuss the fish and wildlife problems that will arise with project development and the possibilities of providing new or increased facilities for fish and wildlife propagation for both commercial and recreational purposes. (See Part 4 of Volume IV and Part 8 of Volume VII.)

(1) Present Conditions. The existing fish and wildlife developments, both natural or manmade, and commercial or recreational.

(2) Protection. The special problems that will arise with project development in providing protection to existing fish and wildlife resources, and the remedies planned.

(3) Needs for New Developments. The need for and desirability of new or expanded fish and wildlife facilities.

(4) Propagation. The possibilities and plans for providing new or increased facilities for fish and wildlife propagation as a part of the project.

(5) Evaluation of Benefits. The evaluation of fish and wildlife conservation benefits or damages that will result with project development.

RECREATION

M. This chapter should present the needs and possibilities of utilizing project waters or works, such as reservoirs, for public recreation. (See Part 7 of Volume VII.) The material can be arranged as follows:

(1) Population. The population in the area that could be considered as served by the project recreational facilities, and the population growth trends.

(2) Existing Facilities. The type and capacity of existing recreational facilities.

(3) Recreational Needs. The recreational needs of the population, based on an appraisal of the existing and potential demands, and an appraisal of probable attendance and use of the project's recreational facilities.

(4) Potential Development. The possibilities and plans for providing public recreational facilities as a part of the project, including consideration of monetary returns and operation costs.

(5) Evaluation of Benefits. The economic and social values and the evaluation of the benefits of the project's recreational facilities.

STREAM POLLUTION ABATEMENT

N. This chapter should cover the needs and possibilities of providing for abatement of stream pollution arising from such problems as inadequate sewage treatment and disposal, contamination from industrial plants, or salt-water intrusion. (See Part 4 of Volume IV and Parts 4 and 5 of Volume VII.)

(1) Present Conditions. The general situation under present conditions.

(2) Stream-pollution Problems. The location, source, character, and extent of the stream pollution at present and as anticipated in the future.

(3) Water Requirements and Treatments. The additional flows required to be maintained in the stream or the special water or sewage treatments required to abate the polluted conditions.

(4) Potential Developments. The possibilities and plans for providing for pollution abatement as a part of the project.

(5) Evaluation of Benefits. The evaluation of the benefits of the pollution abatement that will be accomplished with project development.

O. This chapter should include the effects of proposed developments on existing navigation facilities, and the possibilities of providing new navigation works as a part of the project. (See Part 4 of Volume IV and Part 6 of Volume VII.) NAVIGATION

(1) Present Development. The existing navigation facilities that will be affected by proposed developments and the character and amount of present traffic.

(2) Need for Navigation Works. The need and desirability of maintaining present navigation channels and of providing additional navigation facilities, with emphasis on the probable traffic loads and with full consideration of the transportation facilities now available to the area.

(3) Water Requirements. The water requirements for maintaining present and anticipated navigation channels.

(4) Potential Development. The possibilities and plans for providing and maintaining navigation facilities as a part of the project.

(5) Evaluation of Benefits. The evaluation of the navigation benefits that would result from project development.

P.★This section should present an appraisal of all measurable direct and indirect benefits attributable to the project, a summary of all Federal and non-Federal costs, and a determination as to whether or not the proposed project plan is economically justified. (See Volume XIII.) ECONOMIC ANALYSIS

(1) Direct Effects. Summarize the direct effects of the project in terms of irrigation benefits, power benefits, flood control benefits, fish and wildlife conservation, and similar effects. Show in a summary table the net monetary evaluation of all the measurable direct benefits.

(2) Indirect Effects. Summarize the indirect effects arising as a consequence of the direct benefits.

(3) Costs. Determine annual equivalent Federal costs and annual equivalent private costs for the period of analysis.

(4) Benefit-cost Ratio. Determine total net annual equivalent benefits for the period of analysis by considering development period and deducting private annual equivalent costs. Derive the over-all project benefit-cost ratio, which is the ratio of the net annual equivalent benefits to the annual equivalent Federal costs.★

Q.★This section should present the cost allocation and summarize the financial studies for irrigation, power, and municipal and industrial water to show whether or not the proposed project plan is financially feasible. (See Volumes XIV and XV.) FINANCIAL ANALYSIS

(1) Cost Allocation. Summarize Cost Allocations in accordance with instructions contained in Volume XIV, Cost Allocations.

(2) Repayment. Summarize the repayment determinations of each revenue-producing function of the project and the over-all repayment possibilities of the project plan. Indicate the period required for repayment and probable repayment by each function. Present conclusions as to the feasibility of the project. A payout analysis is required in accordance with instructions of Part 4, Volume XV.

ALTERNATIVE PLANS

R. The chapter on alternative plans should present a full discussion of alternative plans considered indicating the extent of investigations made, the advantages and disadvantages of the alternate plans, and the reasons why the adopted plan was selected rather than any other alternative plan studied.

OTHER AGENCY REPORTS

.10 Reports prepared by other Department of the Interior agencies to be submitted as part of a project planning report should be reproduced as separate reports and included appropriately as part of the substantiating report. These reports have equal status with the substantiating report of the Bureau of Reclamation. ★In addition, and when appropriate, available information or reports from the Bureau of Mines and Geological Survey regarding the possibilities for furthering the purposes of the "Stock Pile Act" (60 Stat. 596) should be included in the substantiating report. This Act refers to strategic and critical materials.★

APPENDIXES

.11 Appendixes shall be prepared covering each major phase of the investigation for a basin, subbasin, or project report. Their text need not be lengthy but should, with accompanying tables and other supporting data, provide for a full technical understanding of the subject treated. The records of any public hearings (see Part 6) held in connection with investigations leading up to a report will be bound as a separate appendix. In certain cases it may be desirable to include any reports prepared by consultants as a separate appendix.

PREPARATION OF APPENDIXES

.12 An appendix on a particular phase of the investigation and report should usually be prepared at the Regional or operating office level by qualified personnel assigned to and responsible for the accomplishment of that phase of the investigation. Due credit should be given to these individuals in the appendix.

SCOPE OF APPENDIXES

.13 Each appendix shall be a complete and accurate record of one phase of an investigation and must reflect all source material, records, computations, pertinent designs and estimates, and conclusions. Lists of maps, profiles, notebooks, etc., indicating the places where filed, and similar records of core and drill samples should be included as appropriate.

SUBMISSION OF REGIONAL DIRECTOR'S REPORT

.14 The Report of the Regional Director (with supporting report and required appendixes) for a basin, subbasin, or project shall be completed in preliminary draft form and submitted to the Commissioner and other appropriate offices as described in Chapter 4.9. The further processing of this report until it reaches the Congress is described in Chapter 4.9.

DISPLAY CHARTS

.15 Presentation of basin plans and projects to the Committee of the Congress, the Bureau of the Budget, and others, are implemented by the use of suitable wall charts depicting the major features of the basin or project plan. Such wall charts shall be prepared and submitted by the Regional Director subsequent to the submission of the final Report of the Regional Director and upon request of the Commissioner. Techniques to be used in preparing such display maps are discussed in Chapter 4.10. In the case of

favorable reports, it may be desirable to prepare this chart in advance of the submission of the final draft of the report and to include a reproduction of this chart reduced to the appropriate scale as an illustration in the Report of the Regional Director.

CHAP. 4.3 DEFINITE PLAN REPORT

GENERAL

.1 The purpose of a basin, subbasin, or a project report described in Chapter 4.2 is to present a comprehensive plan for orderly development and conservation of water and related resources, and to ascertain the probable engineering and financial feasibility to a degree sufficient to enable recommendation for or against further work on the plan. Considerable detailed studies and exploratory work usually remains to be done following this stage before sufficient data are available to initiate the preparation of final plans and specifications. In some cases, projects may be authorized by the Congress before the investigations have been completed, documented, and reviewed even though adequate data may be available to support a favorable recommendation for authorization of a project. Frequently there is a fairly long period between authorization of a project and start of actual construction due to lack of funds as well as to lack of detailed information. In all of these instances there is need for further detailed, documented, and up-to-date information on which to program and develop final plans and specifications for the project. Therefore, following the authorization of a project, there is need for a report on the additional studies including investigations and negotiations consummated prior to construction. This report, known as the Definite Plan Report, may be prepared for the whole project, or for a unit of the project, depending on the size and complexity of the plans recommended for development.

The additional investigations contemplated for the preparation of the Definite Plan Report will be, to the largest extent possible, supplemental to those undertaken for basin, subbasin, or project reports; and accordingly, the scope and content of the Definite Plan Report encompasses information necessary to assure that the basic plan for the project, division, or unit is adequate from engineering, agricultural, and economic standpoints.

Projects or units may be small or large; accordingly, the Definite Plan Report may consist of one volume or several volumes. The first volume in all cases shall include the general plan of development of the project or unit being reported on. This general plan should include the basic engineering, agricultural, and economic determinations required definitely to establish the costs, benefits, probable repayment, and the engineering and financial feasibility of the project. General plans must be well-founded and based on accurate, reliable, and adequate basic data, and are not "general" in the sense of being preliminary or of a reconnaissance nature. The basic data shall be at least equivalent in detail and accuracy to that required for an authorizing report. In the case of land classification, for instance, a detailed survey would be required as specified in Volume V of the Manual.

USE

.2 The Definite Plan Report will be used by all administrative officials and technical personnel of the Bureau as authoritative reference in the preparation of detailed plans and specifications and as the basic guide for carrying out the plans for proper and orderly development of a project, division, or unit. Other important uses are (1) as a basis for scheduling and programing the planning and construction; (2) as the fundamental source of information for budget justifications furnished to the Bureau of the Budget and to Congressional Committees in support of requests for construction funds; (3) as a check to determine the engineering, agricultural, and economic soundness of the plan in its various details of development, or of individual major portions of the plan, before actual construction is undertaken; (4) as a strict guide for the development of the project; and (5) as a source of up-to-date information for members of the Congress, and other officials and interested agencies. Except where required as a basis for additional or modified authorization, the Definite Plan Report will be considered as an internal administrative document of the Bureau of Reclamation and not available for widespread distribution. As a rule, copies of a Definite Plan Report are not to be distributed outside of the Department of the Interior without prior approval of such distribution by the Commissioner.

POLICY

.3 The requirements for the preparation of Definite Plan Reports shall be governed by the following general policy:

POLICY (Cont.)

A. A Definite Plan Report shall be prepared, following authorization for each authorized project; in the case of large projects, it may be prepared for a division or unit of a project. The preparation of the Definite Plan Report shall be financed from allotments for advance planning from General Investigations funds, except that on projects already authorized for which construction appropriations are available, the Definite Plan Report shall be financed from such construction funds.

B. Where actual construction has not yet begun on an authorized project, or in the case of large projects, a major division or unit of an authorized project, a Definite Plan Report shall be submitted by the Regional Director to the Commissioner for his approval, and his approval shall be required before specifications for construction are prepared for the project, division, unit, or any identified property as the case may be. An identified property is a major structure, such as a dam, power plant, siphon, tunnel, canal, or transmission trunk system, permanent camp or facilities, etc. (Identified properties are defined in Paragraph 23.1.2, Volume XXIV.)

C. Where the physical works of an authorized project, such as diversion works, actually are under construction at the time of first issuance of this chapter of the Reclamation Manual, that construction shall not be delayed merely to await approval of a Definite Plan Report on that or those features. However, except as exempted by the Commissioner, specifications shall not be prepared for other features of the project, division, or unit until the Definite Plan Report on such unit, division, or entire project, as the case may be, has been completed and approved by the Commissioner. In cases where construction is already under way, a volume, or several volumes of the Definite Plan Report, if required, shall also be prepared, post-facto, for those features of the project or unit plan which are already under construction. These volumes will outline the general plan and the basis upon which design and construction has proceeded upon features which are already under construction, or completed and will show clearly their relation to the project or unit features yet to be undertaken.

D. If the parts of the report upon which authorization of the project or unit was obtained, provide sufficient data to initiate the preparation of designs and estimates for specification purposes, and if further investigations show that the plan need not be modified materially with respect to project design, cost, or administration, those parts of the authorizing report may be used directly in the Definite Plan Report. In fact, if the project planning report upon which authorization of a project, division, or unit was obtained is found by the Regional Director to be entirely adequate as to the plan of development from an engineering, agricultural, and economic point of view and for initiating final designs and estimates for specification purposes, then it may be used in its entirety as the Definite Plan Report. If the planning report is deficient in only certain details, then the Definite Plan Report may consist of the verbatim planning report revised to the extent necessary to correct for the changes or deficiencies.

E. On newly authorized projects, or authorized project for which no construction appropriation has been made, the request and justification for the General Investigations appropriation shall include funds for preparation of the Definite Plan Report, under the activity "advance planning." Where a construction appropriation is available, it shall be used to finance the preparation of the Definite Plan Report. The program schedules must allow time for approval of the Definite Plan Report by the Commissioner. The Detail Control Schedule, Form PF-2a, should include flagged action entries for the preparation and initial submission of Definite Plan Reports. Control Schedules, Form PF-2, should indicate the programmed date of initial submission of the Definite Plan Report in the manner now used to show first generation of power and other controlling dates.

F. The primary attention in review of a Definite Plan Report by the Commissioner's staff prior to recommending its approval will be directed

POLICY (Cont.)

to the adequacy and soundness of the engineering and economics of the general plan of development. This includes such matters as the evaluation and coverage of the basic elements of the general plan, such as water supply (quantity and quality), detailed hydrologic and river system studies, suitability of land for prolonged irrigation use, costs, repayment, desires of local interests, etc., which are measures of the soundness or real worth of developing the project or unit.

G. After the Definite Plan Report containing the general plan of a project or unit has been submitted to and approved by the Commissioner, it will not be necessary to submit to Washington supplemental data relating thereto on that particular project or unit so long as development proceeds in accord with the general plan as approved by the Commissioner. The supplemental data, in this case will be submitted to the Chief Engineer and Division of Hydrology, Branch of Project Planning as required for technical review and approval of their respective functions. However, if the approved general plan is modified to such an extent that it would be classified as a major revision as defined in Paragraph 4.3.6A, then approval by the Commissioner of such revision will be required, and such approval will be contingent upon the submission of adequate substantiating data incorporated in and made a part of the Definite Plan Report.

FORM

.4 The Definite Plan Report will be prepared in loose-leaf style to allow for making changes or modifications in the report as may be required due to new data or changes, for example, in scheduling construction, drainage conditions, engineering plans, local agricultural conditions, legislation, interstate compact agreements, or basic data such as water supply, as may occur between the time the first release of the Definite Plan Report is made and construction of a project is undertaken and completed. However, the Definite Plan Report shall be made as one document, but depending upon the circumstances and size of the project or unit, the document may be prepared as one volume or as a series of volumes to be numbered consecutively in an order to be shown in the table of contents. (For revisions, see Paragraph 4.3.9.)

CONTENTS

.5 A Definite Plan Report on a project, division, or unit is to contain the following:

Basic Data

A. Details at least equivalent to those required for a substantiating report as outlined in Chapter 4.2, Volume III, including appendixes and project cost estimates on Form PF-1 (see Volume XXIII), shall be included. This means that the Definite Plan Report must be based upon the detail of information envisioned in Chapter 4.2, and the other Manual volumes pertinent to the subject matter.

Design Data

B. Summary of preliminary design and estimate details required as outlined in Volume IX, for the particular unit, division, or project for which the volume has been prepared shall be included. Such details as the logs of drill holes, topographic maps, special studies related to design, and similar details may be included in supplemental reports for submittal to the Chief Engineer and Division of Hydrology as explained in Paragraph 4.3.3G.

Integrated Functions

C. A general description of the integrated functions of related units, divisions, and the main project shall be included. Often chapters of the preauthorization basin, subbasin, or project reports may be included in their entirety in the Definite Plan Report, especially in those cases where no further details are required before preparation of detailed plans and specifications are requested. (See Paragraph 4.3.3D.) If the Definite Plan Report covers an entire project, it should include details on the general plan for all features involved in the project. If it covers only a unit or division of a project, it should include a detailed description of the unit or division and show exactly how (physically and financially) that unit or division fits into the project. It should also contain a description of the economic and physical relationship of the plan to the region or basin development of which the

Integrated Functions (Cont.)

project, division, or unit is a part. The report, besides covering comprehensively all features and phases of a project, division, or unit, should emphasize the modifications or amplifications of the authorizing report.

In the event the more detailed preconstruction investigations disclose that major modifications in the authorized plan are essential, the Definite Plan Report shall disclose fully what those changes are, and whether, in the opinion of the Regional Director, reauthorization of the entire plan, or any major feature thereof is a legal or policy requirement. In such event, or if otherwise required, the report shall be so phrased, in general accordance with the provisions of Chapter 4.2, that it may also be utilized for the purposes of securing additional or modified authorization.

Summary Sheets

D. Summary Sheets of the project, division, or unit not to exceed about four pages in length shall be inserted in each Definite Plan Report immediately behind the front flyleaf. When a Definite Plan Report is to be prepared in a series of volumes, a copy of these Summary Sheets shall be similarly inserted in each volume so that each volume can be used separately with ease and intelligence. The Summary Sheets shall include basic statistical data for the project; pertinent data on the dam, reservoir, and other principal physical works; on the hydrology, such as drainage area, stream flow, and spillway requirement; on functions served by the project, such as irrigation, power, and municipal water supply; on costs, repayment, and other economic data; and on other important items. Also, a general map of the project with height of 10-1/2 inches should be included. See Illustration 1 for an example of the Summary Sheets.

Related Plans

E. A statement of the relation of the project or unit to the plans of other agencies as disclosed by previous review and comment shall be included when pertinent.

Repayment Organization

F. A review of the action taken by local interests in the formation of a suitable organization for execution of repayment contracts, and the status of present and future plans for negotiations and consummation of agreement with such interests shall be included.

Payout Analysis

G. A repayment study based on the Definite Plan, tentative allocations, and estimated costs and revenues from irrigation, municipal water, and power, prepared in accordance with Part 4, Volume XV shall be included. In addition, year-by-year studies shall be made separately for irrigation and municipal water and power, somewhat similar to the power system average rate and repayment studies now prepared annually in accordance with Volume VI of the Manual. These studies should show the estimated year-by-year data, including estimated revenues; rates for payment; costs, including operation and maintenance, replacement, etc.; net revenues, interest, and amortization payments; and surplus or deficits. These studies will form the basis for the summary payout analysis called for under the first part of this paragraph.

Operating Regulations

H. A plan for the regulation of reservoirs and methods of project operation shall be included. For multiple-purpose projects, this will involve consideration of agreements with other agencies, such as the Corps of Engineers for flood control, the Fish and Wildlife Service for conservation of fish and wildlife, the National Park Service or local agencies for development of recreational facilities, and the consideration of existing and potential water rights, state laws, compacts, treaties, and other related factors.

Hydrologic Operations

I. A general discussion of the plan of hydrologic operation of the project or unit showing the relationship to the hydrologic operation of the entire river basin system shall be included. This discussion should tell how the project or unit and the whole river basin is to be operated for irrigation, navigation, power, flood control, and for such other water uses as are included in the plan of development.

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UNITED STATES
DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Washington 25, D. C.

Approved: March 25, 1953		
Effective: Upon receipt	RECLAMATION MANUAL	VOLUME III BASIN AND PROJECT DEVELOPMENT ADVANCE SUPP. 2
Received:		

Part 4, Planning Reports, Chapter 4.3, Definite Plan Report

1. Paragraphs 4.3.6, 4.3.6A, and 4.3.6B covering instructions for approval of the Definite Plan Report and its revisions, are hereby superseded by the following revised paragraphs; and additional new Subparagraphs 4.3.6C and 4.3.6D requiring approval of revised Official Estimates in Definite Plan Reports and for those projects, divisions, or units of projects exempted from the requirement of a Definite Plan Report:

.6 The Definite Plan Report, including pertinent appendixes or exhibits shall be transmitted by the Regional Director to the Commissioner with a letter including any special recommendations he may deem appropriate in connection with it. Following review, the Commissioner will notify the Regional Director of the approval or other action taken on the Definite Plan Report. The Definite Plan Report containing the general plan (including the basic engineering, economics, and administrative aspects of the plan) must be approved by the Commissioner before the preparation of final designs and specifications are initiated. As long as the project or unit is developed in accord with the approved general plan, the supplementary data, including detailed maps, etc., should be submitted only to the Chief Engineer and Hydrology Branch as required for technical review and use as specified in Subparagraph 4.3.3G, with information copies to the Commissioner, attention 600, when such supplementary technical data on a power resource development have effect on questions of power budget or marketing relations. APPROVAL REQUIRED

A. After a Definite Plan Report has been approved, any major revisions in the Definite Plan must be approved by the Commissioner before proceeding with construction of any parts of the project affected by the major revisions. A major revision shall be considered as anything that changes the location, classification, or the amount of the irrigable land by more than 3 percent or 3,000 acres; changes the reservoir storage capacity by more than 10 percent or 20,000 acre-feet; changes the power generating capacity by more than 5 percent; changes the rate of repayment or repayment period of the project; increases the cost estimate of the total or a significant part of a unit, division, or project by more than 10 percent (as used in this phrase "significant part" means any part of a unit, division, or project of Major Revisions

which the cost of construction equals or exceeds 10 percent of the total estimated cost of that unit, division, or project); changes cost allocations other than those growing out of minor revisions of cost estimates; involves new functions not contemplated in the authorizing report or any change that requires new or additional authorization. However, these criteria do not permit making any change in size or scope of the project, division, or unit plan that is contrary to requirements contained in the project authorization or legislation.

B. Other revisions may be considered minor revisions and may be made by the Regional Director without prior approval of the Commissioner. The Commissioner and other recipients of the Definite Plan Report will be provided with copies of all minor revisions immediately after approval by the Regional Director. — Minor Revisions

C. The official project estimate, Form PF-1, is a part of the Definite Plan. Volume XXIII, Chapter 3.3, contains instructions for revising the PF-1 and requires that "When a revised estimate results from significant changes in the design or scope of a project, the change in plan must first be approved through the Definite Plan Report revision procedure. Approval of the revised Definite Plan Report by the Commissioner will constitute approval of the new estimate of total cost." If a revised estimate exceeds by more than 10 percent the latest estimate approved in the Definite Plan Report by the Commissioner it must be submitted to the Commissioner for approval as a revision to the Definite Plan. — Approval of Form PF-1 Revisions

D. Any major change in scope, or major revision in plan, or increase exceeding 10 percent of the Official Estimate, Form PF-1, for a project, division, or unit of a project exempted from the requirement of a Definite Plan Report shall be submitted to the Commissioner (attention 700, 300, and 200) for approval in the same manner as would be followed if a Definite Plan Report had previously been prepared for that project, division, or unit. Programing documents Forms PF-2, PF-2a, and PF-5 shall not be used as the vehicle for obtaining approval of a major change in scope, major revision of plan, or major change in estimate of cost for construction and rehabilitation activities on Bureau projects. — Reporting Major Changes

2. The following pen and ink change should be made in Paragraph 4.3.9: After the word "revisions" in the first line add the parenthetical phrase: "(including both major and minor revisions)".

3. These instructions will be incorporated in a major revision of Chapter 4.3 presently under way to clarify and simplify the Definite Plan Report requirements.

/s/ Fred G. Aandahl

Assistant Secretary
for Water and Power Development

Distribution: III

J. A statement regarding the location, extent, type, and kind of minerals and archaeological deposits located in the reservoir area, and their possible value and costs of salvage, in cooperation with the Bureau of Mines, Geological Survey, and Smithsonian Institution, shall be included when pertinent. — Minerals Archaeological Deposits

K. The inclusion of essential construction data and plans as developed during preconstruction activities, including a project Control Schedule, Form PF-2, prepared in accordance with Volume XXIII should be included. This Control Schedule will form the basis of subsequent approval as to construction funds and budgetary requirements by the Commissioner. The report also shall include a proposed schedule showing timing of repayment contract negotiations, plans for bringing into use each block of irrigated land, and any related settlement on development activities. Similarly, it shall show schedules for providing domestic or municipal water, pumping or commercial power, project acreage, total irrigable and net irrigable acreage, and any type of service to be rendered by the Bureau under the terms of the project authorization. (See Part 4, Payout Analysis, Volume XV.) — Program Schedules

L. Essential data on actual project boundaries established by detailed land classification, economic studies, and finally as included in district formation shall be included when pertinent. — Project Boundaries

M. Names, descriptions, and over-all chracteristics of each power generating development, shall be given when pertinent. — Power Generating Facilities

N. Outline of the trunk-line transmission of the project, including a single-line diagram, capacities of main components of a transmission system, and a brief statement with regard to the extent of the transmission-system development to be considered a part of the plan described, shall be included when pertinent. For further details, see Volume VI, Power. — Transmission

.6 ~~The Definite Plan Report, including pertinent~~ appendixes or exhibits shall be transmitted by the Regional Director to the Commissioner with a letter including any special recommendations he may deem appropriate in connection with it. The Commissioner will notify the Regional Director of the approval or other action taken on the Definite Plan Report. The report containing the general plan (the basic engineering, economics, and administrative aspects of the plan) must be approved by the Commissioner before the preparation of final designs and specifications are initiated. As long as the project or unit is developed in accord with the approved general plan, the supplementary data including detailed maps, etc., should be submitted only to the Chief Engineer and Division of Hydrology as required for technical review and use as specified in Paragraph 4.3.3G. — APPROVAL REQUIRED

Superseded Adv Sup 2

A. After a Definite Plan Report has been approved, major revisions in the Definite Plan must be approved by the Commissioner before proceeding with that part of the project affected by the major revisions. A major revision shall be considered as anything that changes the amount or location of the land to be irrigated, changes the repayment period of the project, increases the cost estimates, changes cost allocations, involves new functions not contemplated in the authorization report or any change that requires new or additional authorization.

B. Minor revisions may be made by the Regional Director without prior ~~approval of the Commissioner.~~ (See Paragraph 4.3.9.)

.7 Definite Plan Reports (on the general plan) will be processed in the Washington office by the Branch of Project Planning. Immediately upon receipt of a Definite Plan Report, the Director of Project Planning, or his representative, will circulate copies of the report to each of the following for views and recommendations: — REVIEW OF DEFINITE PLAN REPORTS

REVIEW OF DEFINITE PLAN REPORTS (Cont.)

Director, Branch of Operation and Maintenance
Director, Branch of Power Utilization
Chief Counsel
Director, Office of Programs and Finance
Assistant to the Commissioner (Engineering).

(Note: The Chief Engineer and the Chief, Division of Hydrology, Branch of Project Planning, receive copies direct from the region.)

The Director of Project Planning will, after consultation with the Commissioner, specify the period allowed to review the report. Upon receipt of comments, a letter to the appropriate Regional Director will be drafted for the Commissioner either approving or not approving the Definite Plan Report. If it is not approved, the specific reasons therefor, as well as instructions for future action, will be given. The comments of the Chief Engineer, and Chief, Division of Hydrology, Branch of Project Planning, and all branches and offices concerned will be properly cleared prior to final preparation of the Commissioner's letter. The Regional Director shall reproduce substitute copies of any changed pages, and if the Commissioner approves a Definite Plan Report with conditions, the letter or document setting forth the conditions will be reproduced by the Regional Director, who shall send copies to all recipients of the reports for insertion therein. (See Paragraph 4.3.9.)

COPIES .8 In order to expedite review and approval of the Definite Plan Reports, the following are required:

A. At least 50 copies of each such report shall be made initially. Copies shall be numbered consecutively. This same procedure shall apply whether the Definite Plan Report is prepared in one or more than one volume. Ordinarily only six to twelve copies of the appendixes should be made unless more are needed in special instances.

B. The Regional Director shall submit the following number of copies of the main report general plan and appendixes, if any, as follows:

	Main Report	Appendixes
To the Commissioner, attn 700	Nos. 1-20, incl	2
To the Chief Engineer, Denver	Nos. 21-27, incl	2
To Hydrology Division (Project Planning) Denver	Nos. 28-30, incl	1

C. The Regional Director shall retain the remaining copies for use within the Region.

D. At the time the Definite Plan Report is forwarded to the Commissioner, the Regional Director will send separately 50 copies of the Summary Sheets of the project as outlined in Paragraph 4.3.5D (see Illustration 1) and 50 copies of the General Map (10-1/2 inches high) of the project.

F IDENTIFICATION OF REVISIONS .9 A sheet noting revisions that are made from time to time shall be submitted with revised sheets of the Definite Plan Report. Such sheet, brought up to date by the Region, shall be inserted in the report by the report holder upon receipt of the revision. The revision sheet, which is signed and dated by the Regional Director or by his representative, shall be in the form as shown by Illustration 2. Each page of the report that is revised shall show a revision number and date in the lower left-hand corner. New pages covering the first revision of the report shall be numbered "Rev. No. 1" with date shown, and the second "Rev. No. 2," and so on. Each revision shall be distributed by the originating office by the up-to-date revision sheet, and the distribution shall be in accord with the original distribution of the report as specified in Paragraph 4.3.8B. Complete files of all revisions shall be kept by the project office and by the Regional Office.

SUMMARY SHEETS

EXAMPLE ONLY
Data do not represent actual project conditions.

SUMMARY SHEETS

Sageflat Unit, Hypothetical Division, Dusty River Basin Project

LOCATION: Western Drystate, on Sageflat River, 10 miles south of Gopherhole, Region X.

AUTHORIZED: May 20, 19xx by Act of Congress (P.L. 324, xxth Congress, 2nd Session). See Planning Report No. 10-20.300-2.

PLAN

Construction of Highplain Dam and Reservoir on Sageflat River in Salt County, Drystate will regulate runoff for irrigation of 50,000 irrigable acres of new land (total project area 65,000 acres; net irrigable area 48,000 acres) in the Dusty River Basin, in Salt, Dune, and Desolation Counties. Lands will be irrigated from the 100-mile long Allstate Main Canal which will divert by gravity from Highplain Dam and Reservoir. The Sageflat Division will furnish municipal water to six towns (Gopherhole, Frontier, Sagetown, Midway, Plainsville, and Brush). A power plant with installed capacity of 60,000 kw will be constructed at the dam to supply existing and expanding power needs in western Drystate for commercial use and irrigation pumping. Repayment will be completed in 50 years or less for all costs allocated to irrigation, municipal water, and power. Any surplus revenues from power will be credited to the Dusty River Basin account as authorized. In addition, substantial benefits will be provided for flood control, fish and wildlife, recreation, and sediment control.

DEFINITE PLAN REPORTS

Vol. 1 ..... General Plan of Sageflat Unit, Hypothetical Division
Vols. 2-12 ... To be scheduled

COSTS $50,000,000

Dam and Reservoir	$26,000,000
Power Plant and Power Lines	18,000,000
Municipal Pipe Line	1,000,000
Canals	2,000,000
Distribution System	2,000,000
Drainage System	1,000,000

SUMMARY SHEETS (Continued)

BENEFITS, ALLOCATIONS, AND REPAYMENT

	Benefits (Annual)	Allocation (Tentative)	Repayment
Irrigation	$2,000,000	$20,800,000	$10,000,000
Municipal Water	250,000	1,200,000	2,000,000
Power	1,850,000	20,000,000	30,000,000
Flood Control	700,000	5,000,000	
Fish and Wildlife	90,000	1,000,000	
Sediment Control	110,000	1,000,000	
Recreation	100,000	1,000,000	
	$5,100,000	$50,000,000	$42,000,000

IRRIGATION

	Class 1	Class 2	Class 3	Total or Average
New irrigated acreage (gross)	25,000	20,000	5,000	50,000
Payment capacity/ac/yr	$8.00	$6.50	$4.00	$7.00
O&M & replacements/ac/yr	2.00	2.00	2.00	2.00
Amortization capacity/ac/yr	$6.00	$4.50	$2.00	$5.00

Repayment period (after 10-year development period) ..... 40 years
Farm Units: At present 3 under 160 acres; 10 161-320 acres; and 5 over 320 acres.
Farm Units: Anticipated, 50 under 100 acres; 200 101-160 acres; and 50 161-320 acres.
Growing season ..... 125 days
Elevation of project area ..... 4500 msl
Consumptive use requirement, av ann. ..... 2.30 ft
Effective precipitation, av ann. ..... .80 ft
Diversion requirement, av ann. ..... 3.20 ft

	Main Canal	Brush Main Lateral
Length	100 miles	50 miles
Maximum capacity	1,000 cfs	400 cfs

First water to be applied ..... June, 19xx
All project lands to be irrigated ..... May, 19xx

MUNICIPAL WATER (only untreated water furnished)

Average annual charge per ac-ft $14.00
Average annual O&M per ac-ft 4.00
Average annual repayment per ac-ft $10.00

Municipal water users to repay costs in 50 years with 2 percent interest.1/
Average annual water demand ..... 4,000 ac-ft

Gopherhole	1,000 ac-ft	Midway	500 ac-ft
Frontier	800 ac-ft	Plainsville	400 ac-ft
Sagetown	700 ac-ft	Brush	600 ac-ft

Pipeline ..... 40 miles long .... 20 cfs maximum capacity.

1/ For purposes of this example, 50 years was used for the repayment period.

SUMMARY SHEETS (Continued)

POWER (Sageflat Power Plant)

Installed capacity (4 @ 15,000) ..... 60,000 kw
Operating head ..... 150-200 ft
Transmission Lines:
Sageflat to Gopherhole, 200 kv ..... 60 miles long
Sagetown to Brush, 115 kv ..... 75 miles long

	Annual Production	Average Rate
Firm commercial	300,000,000 kw-hr	5.0 mills
Nonfirm commercial	50,000,000 kw-hr	3.0 mills
Irrigation pumping	25,000,000 kw-hr	2.0 mills

Estimated Annual O&M and replacements $400,000
Net power revenues (after O&M and replacements) $1,300,000
Power revenue sufficient to repay power allocation at 3% interest in 21 years.
Power will subsidize irrigation $10,000,000
Interest $7,350,000
All net revenues, 2 years ... 2,650,000

Power revenues after 23 years will be credited to Dusty River Basin account.
(Net revenues 24th to 50th year, incl. = $35,100,000.)

DAM

Located on Sageflat River, 10.2 miles upstream from Gopherhole
Type ..... rolled earthfill
Maximum structural height ..... 260 ft
Volume ..... 5,000,000 cu yds
Spillway capacity ..... 100,000 cfs

RESERVOIR

Elevation at maximum controlled storage (500,000 ac-ft) ..... 6620 msl
Active storage ..... 440,000 ac-ft
Capacity below bottom outlets ..... 60,000 ac-ft
Storage allotted as follows:
Irrigation ..... 200,000 ac-ft
Flood Control ..... 100,000 ac-ft
Power ..... 100,000 ac-ft
Municipal Water ..... 20,000 ac-ft
Fish and Wildlife ..... 5,000 ac-ft
Sediment Storage ..... 75,000 ac-ft
500,000 ac-ft

HYDROLOGY

Drainage area above Highplain Dam ..... 2,500 sq mi
Annual runoff, average (1910-1978) ..... 2,000,000 ac-ft
Annual runoff, maximum (1961) ..... 4,000,000 ac-ft
Annual runoff, minimum (1934) ..... 1,000,000 ac-ft
Peak discharge of record (June 1961) ..... 65,000 cfs
Minimum discharge of record (Aug. 1934) ..... 50 cfs
Inflow design flood, volume 10 days ..... 1,000,000 ac-ft
Inflow design flood, peak discharge ..... 130,000 cfs

SUMMARY SHEETS (Continued)

REMARKS

The Sageflat Irrigation District has been organized in accordance with state law and has submitted written statements to the Regional Director and Commissioner indicating a willingness to repay irrigation costs up to the limit of their probable ability to repay as determined by economic studies of the Bureau of Reclamation.

REVISION SHEET

The Revision Sheet, size 8 x 10½ inches, is to be prepared in the region and used for distributing the revised pages to recipients of the report. The revised pages, including the illustrated "Revision Sheet" are to be inserted in the Definite Plan Report by the report holder.

EXAMPLE ONLY ENTRIES do not represent actual project conditions.

Unit, Division, and Project name.

DEFINITE PLAN REPORT
SAGEFLAT UNIT, HYPOTHETICAL DIVISION
DUSTY RIVER BASIN PROJECT
- - -
REVISION SHEET

REVISION		PORTION OF REPORT AFFECTED	REVISION INSERTED*	
NO.	DATE		BY	DATE
1	10-12-81	Pages 10, 22, and 39, Vol. I.		
2	6-2-82	Pages 90, 102, and 133, Vol. II, and pen and ink correction Page 134, line 4, changing total from $12,468,000 to $14,500,000.		
3	8-10-82	Page 20 and 55, Vol. I, and Table 6, Appendix II. Also pen and ink changes to Pages 60, 72, 80, 83, 87, 90, 100, 120, 130, 133, and 150 as shown on attached Supplemental Revision Sheet.		

These columns to be filled in by the region. Each time a revision is made, a new up-to-date sheet is to be distributed to holders of copies of Definite Plan Reports.

Margins

1½" ½" 3/4" 3 3/4" ½" ½" ½"

Revision Sheet to be dated and signed by Regional Director or by his representative.

*To be filled in by recipient of Revision Sheet

Date: August 10, 1982

Signature _____
Regional Director

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.1 A reconnaissance report is a report addressed to the Regional Director for his advice in preparing his investigations program. * When a reconnaissance report has been approved by the Regional Director, copies of the report should be furnished the Commissioner for information. (See Paragraph 4.9.17.)* The reconnaissance report is based on an analysis of existing data and the results of reconnaissance field investigations. It presents information on the potentialities of land, water, and related resource development in a given area. Its main purpose and use is to indicate whether further detailed investigations are justified and, if so, to outline the scope of such investigations together with an estimate of the time and funds required for their completion. (See Chapters*2.2,*4.8 and 4.9.) Reconnaissance reports may also be used to support comprehensive basin plans. GENERAL

.2 Reconnaissance reports cannot be standardized readily because they cover a wide range of conditions and are restricted to the available information or that which can be obtained within the scope of the investigation. In general, the report will present the same type of information that would be included in a basin or project report (see Chapter 4.2), but in briefer and less detailed form. As a minimum, however, the information will be presented under six main headings: FORM & CONTENT OF REPORT

A. General history and description of area, including a review of resource investigations and surveys.

B. Area or project lands, with emphasis on those considered potentially irrigable.

C. Water supply, requirements, and utilization.

D. Plan of development, including the possible multiple uses and a listing of all existing reservoir and all known potential reservoir sites worthy of mention.

E. Economic analysis.

F. Conclusions and recommendations, including outline and estimates for further investigations if recommended.

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SURVEYS ON EXISTING PROJECTS

.1 From time to time need develops on existing Reclamation projects--that is, those projects where construction by the Bureau has been accomplished, the land settled, and irrigation is being practiced--for general surveys, or checkups as to the physical and economic conditions on the project and their effect on the prosperity of the farmers and the security of the investment of the United States in the project. These are to be considered as planning reports where a major change in the project plan may be contemplated or where a new or additional authorization in accordance with Reclamation Law is required. The need for a survey may be called to the attention of the Bureau by the water users in a formal request for assistance in various forms. The water users may request postponement of their current annual charges due the United States; they may ask for an amendatory repayment contract which will make annual payments easier to meet; and they may request that special betterment work programs be instituted to improve the operating efficiency of the irrigation system. On the other hand, the Bureau may determine that such surveys and work programs are necessary to maintain the project in the best condition.

REHABILITATION & BETTERMENT SURVEYS

.2 In the majority of cases where a survey of the physical setup is made, the survey results in a rehabilitation and betterment work program which may be completed in 1 year or may be of such extensive character that a period of several years is needed. In only a few cases, however, does the survey of need for rehabilitation work on existing projects result in any change in the project plan.

REPORTS ON WORK NEEDED

.3 In all cases where surveys are made on existing projects to determine the nature and extent of rehabilitation and improvement work that needs to be done, detailed reports shall be prepared. These reports will differ in content according to the nature of the survey. It is the responsibility of the Regional Director to see that these reports are broad enough to meet the problems encountered, in order that the Commissioner may be able to determine what action shall be taken to carry out the program, and to present the need to Congress, if funds are to be appropriated. Details as to rehabilitation and project betterment work are covered in Part 2 of Volume XVI.

FINANCIAL ADJUSTMENT REPORTS

.4 Reports on the detailed economic condition of existing projects, where required, are made by project officials under the direction of the Regional Director. These reports may cover a variety of matters, such as land classification, farm incomes, marketing facilities, and extent of settlement, all of which bear on the capacity of the water users to repay their obligations to the United States. (See Chapter 4.9 in regard to the processing of these reports.) Details concerning reports on economic conditions, or discussing the need for financial adjustments on operating projects, will be found in Part 2 of Volume XV.

CHAP. 4.6 POWER PLANNING AND MARKETING REPORTS

POWER PLANNING & MARKETING REPORTS

.1 The development of power resources and utilization of those resources involves broad overall planning and consideration of many complex engineering and economic studies. Reports for such power planning and marketing are prepared in regional offices, usually under the direct supervision of the Power Manager, as a responsibility of the Regional Director. The planning work for such reports will follow the procedure set forth in this Volume and in Chapters 2.2, 2.3, and 2.4 of Volume VI. When such a report is a part of a more comprehensive project planning report on a multipurpose project, close collaboration between the Branches of Power Utilization and Project Planning will be necessary to insure that the power development is properly coordinated with the overall project development. Also, the overall project development must include proper consideration of power development to assure optimum development and utilization of power, consistent with other prior uses of water.

.1 As indicated in Chapter 4.1, special-purpose reports present the findings and conclusions of special investigations and studies which are required to satisfy specific requests or legislation; to meet critical problems associated with only one phase of a development; or to provide information on specific phases applicable to more than one development. It is not possible readily to circumscribe the scope of special-purpose reports and the use that may be made of the results. SCOPE

.2 The content of each special-purpose report will be restricted to, and developed in accordance with the particular investigation, or phase thereof, being reported upon. For this reason the organization of each report should be varied to permit the most effective presentation. Each report, however, should present a clear statement of: FORM & CONTENT OF REPORT

A. The problem under consideration or investigation, and being reported upon.

B. The available results pertinent to the solution of the problem.

C. The procedure followed in the investigation or studies.

D. Presentation of the results of the investigations and conclusions that are warranted.

.3 The following are examples of special studies, investigations, problems, or phases thereof, and purposes for which the special-purpose report may be prepared: EXAMPLES

A. Investigations and studies of drainage conditions on irrigated and potentially irrigable lands (see Paragraph 4.7.4).

B. Allocation of construction costs (see Paragraph 4.7.5).

C. Special market outlet surveys (see Paragraph 4.7.6).

D. Information for local interests and the public for public hearings (see Paragraph 4.7.7).

E. Information on status of investigations or the suspension of investigations resulting from curtailment of appropriations (see Paragraph 4.7.8).

F. Interim inventory reports and factual or informative reports on special purposes (see Paragraph 4.7.9).

G. Supplemental information and summarized data for administrative use in the Commissioner's office on projects and units recommended for authorization in basin planning reports and on those units of basin plans already authorized by the Congress for which detailed information is not available (see Paragraph 4.7.10).

.4 A special-purpose report on drainage may be required where conditions with respect to this particular aspect of a project are of a character to justify making an investigation and presenting the findings without covering all other features of the project. (See Chapter 2.9 of Volume XVI.) The report, if of a reconnaissance nature, is used as a basis for formulating a program for additional investigations, and if of a detailed nature, is used as a basis for determining the feasibility of the drainage plan or for constructing drainage facilities. The drainage report should include information on: DRAINAGE REPORT

A. The general make-up of the project including the existing irrigation system or the plan for a proposed irrigation system.

B. The outlet conditions or whether a satisfactory drainage outlet is available and can be obtained at reasonable cost.

DRAINAGE REPORT (Cont.)

C. The topography and surface drainage conditions or whether the slope of the land will permit the construction of drains that will function satisfactorily.

D. The soils, subsoils, and substratum conditions of the area and whether they are of a permeable nature and susceptible of drainage.

E. Comparative land use, that is, the value of the lands under existing conditions compared with their value if drained and developed under a successful irrigated agriculture.

F. The groundwater conditions or the extent of the area having a high watertable and the degree to which crop production is affected.

G. The capacities of the drains, or the rates of runoff that should be provided for in designing such improvements, and the hydrologic studies including rainfall, runoff, infiltration, underground flow, and seepage.

H. The plan, and design, of drainage improvements whether by open ditches, tile, pumps, or any combination of the three.

I. The estimates of costs and the evaluation of benefits, both direct and indirect, that are expected to result from the drainage improvement.

J. The repayment ability of the water users and the feasibility of the drainage construction.

COST ALLOCATIONS REPORT

.5 A special-purpose report on the allocation of construction costs may be required for reasons such as (1) special legislation recognizing the propriety of allocations to purposes not covered in the original authorization of the project, and (2) changes in certain aspects of the project such as the costs, the benefits, and the project plan.

A. The cost allocations report should include:

(1) Background information concerning the undertaking of the project, including a brief legislative history of the project.

(2) A summary description of the project.

(3) A description of each of the purposes of the project setting forth in each case the pertinent information regarding the establishment and operation of the project purpose that may affect the allocation problem.

(4) A presentation of the cost estimates of the project construction giving sufficient detail to identify the total project costs, the specific costs for each project purpose, and the joint costs.

(5) A summary of the procedure followed to apportion and assign the joint costs to the project purposes.

(6) The findings or conclusions of the allocation investigation. (See Volume XIV for further details on cost allocations.)

MARKET OUTLET REPORT

.6 In some instances, it is necessary to make investigations of market outlets for specific agricultural products and to present in a special report the findings for use in planning. This is particularly true when a specific crop comprises the major product of a number of projects and the product is subject to variations in the location and extent of demand as well as to competitive supply. Under these conditions, the investigation of project economics is dependent upon a sound appraisal of the outlook for the specific crop. The report should present a review of past production and consumption, including the general problems involved, an analysis of potential production markets and prices, and conclusions and recommendations regarding the future outlook for the product. An example of this type of report is the "Market Prospects for Washington Apples and Certain Other Fruits" prepared for Region 1.

PUBLIC HEARING REPORT

.7 Occasionally, public hearings are held to explore local public reaction to plans contemplated by the Bureau, and to determine the willingness of affected interests to cooperate, under the Reclamation Laws, in the development of the plans. In order to permit local interest to have first-hand knowledge of such plans, it is sometimes desirable to prepare, and distribute prior to the hearing, a suitable report which presents these plans. The report shall be so prepared as to enable the local interests to acquaint themselves readily with the work accomplished by the Bureau in developing its plans for the area and with the problems, alternatives, or controversies, as the case may be, upon which the local people are being requested to express themselves. The report shall not present any recommendations but shall present factual data on the investigations conducted up to that time and findings thereon that will be of interest to the public. (See Chapters 4.9 and 6.1.)

STATUS REPORT

.8 A status report is merely an information document to summarize the work performed on an investigation at a given date. The reports are usually for use within the Bureau but may be submitted to local or state interests for their information. They are also prepared as "wrap-up" reports to present information on the status of investigations and to preserve field data already collected when curtailment of funds or other factors necessitates suspension of the investigations. "Wrap-up" reports shall be complete in their presentation of the factual data which are used to evaluate the extent to which investigations have progressed, by whom they have been performed, and where the data are filed. It is extremely important that the report be complete in this respect in order that personnel assigned to reactivation of the investigations can become fully apprised of the status of those investigations when suspended, and of the amount of work remaining to be accomplished for completion of the investigations and preparation of the planning report.

INTERIM REPORT

.9 An interim report may be prepared when a factual report is desired for some special purpose. The inventory report on the Colorado River Basin is an example of this type of interim report. (See "The Colorado River," March 1946, published by the Department of the Interior). The interim report may also be used for very large projects, for the purpose of recommending authorization of an initial stage of development for the project. In this form, it is actually a project report. (See Chapter 4.2 for the preparation of a project report.) The interim report, when used for stage development, shall show in a broad manner how the initial development being recommended for construction will fit in with an ultimate plan of development. When used for this purpose, the report shall be prepared in general accordance with instructions for planning reports (see Chapter 4.2).

SUMMARIZED DATA REPORT

.10 A basin planning report generally includes a recommendation for the immediate authorization of several projects or units of the basin plan. As soon as the preliminary draft of a basin report is submitted to the Commissioner, preparation of a brief summary report (usually varying from 5 to 10 pages) on each of the units recommended for immediate construction in the basin report shall be initiated unless a project planning report on the unit, presenting the same plan as included in the basin report, already has been prepared. Summarized data reports shall also be submitted for those projects or units of basin plans already authorized by the Congress, such as the Missouri Basin Project, and for which no project planning or definite plan report has yet been prepared. Such reports are required for administrative use in the Commissioner's office to furnish more detailed information on these units than is included in the basin report, which in the interest of brevity, must limit such description to extremely short statements. The submission of these reports does not preclude the preparation of the requisite planning report on the project or unit. The summary report on an initial unit shall give a brief general description of the proposed development, and shall include a map of the project and may include graphs and illustrations to supplement the text. It shall include very brief discussions of the following items pertaining to the proposed unit:

SUMMARIZED DATA REPORT (Cont.)

A. Authorization.

B. Location and purpose of project.

C. Climatological data.

D. Project area.

E. Present and future land utilization.

F. Water supply and water rights.

G. Project plan.

H. Repayment.

I. Project costs and benefits.

J. Relation of project development to basin plan.

K. Negotiations with local interests.

L. Status of field investigations.

M. Status of preconstruction data.

N. Construction schedule.

CHAP. 4.8 UNFAVORABLE FINDINGS IN PLANNING REPORTS

.1 Project planning reports for all projects, activities, or developments which are investigated in accordance with Reclamation Law and found to be physically infeasible, economically unsound, or undesirable for any other reason, shall be submitted to the President and to the Congress. This policy and the instructions contained in following paragraphs shall apply to all planning activities for which planning reports are prepared. It is not intended that an adverse recommendation on a project shall constitute a permanent appraisal. Consequently, sufficient leeway should be preserved in the recommendation and report discussions to permit re-examination of the project in the future when changed conditions might so justify. By submitting unfavorable reports on undesirable potential projects, or any other planning activity, it will be possible to dispose of investigations and reports for which, heretofore, there has been no satisfactory positive action taken. POLICY

.2 There are no exact criteria for determining what constitute sufficient reasons for recommending adversely on a potential project, activity, or development. The decision in most cases will be one dictated primarily by judgment. The Regional Director shall make the decision as to the nature of the recommendation before submitting the report to the Commissioner's office. The Commissioner reserves the final decision as to the recommendations so far as the Bureau of Reclamation is concerned. Although no exact criteria can be set out to define the basis for submitting an unfavorable report, the following may be considered as guides: CRITERIA

A. A project, development, or planning activity that is physically infeasible should not be recommended. Projects in this category include those with inadequate or unsuitable water supplies, poor lands, structurally deficient damsites, and so forth.

B. A single-purpose power project which cannot pay out its own investment within a reasonable period of years, at the interest rate prescribed by Reclamation Law, should not be recommended.

C. A project, development, or planning activity for which the ratio of benefits to costs is not more favorable than 1 to 1 should not be recommended.

D. A project should not be recommended when the prospects for repayment of its ordinarily reimbursable costs are unfavorable unless particular circumstances justify its recommendation. The decision on how unfavorable these repayment prospects must be before an adverse report is submitted to Congress is most difficult and requires sound judgment. Exceptionally strong arguments must be presented in order to recommend authorization for a project if, despite the fact that its benefits exceed costs, the sum of anticipated revenues (power, irrigation, and other water uses) will not be sufficient to relieve, in addition to the operation and maintenance costs, its reimbursable construction costs within a reasonable period of years. As a guide only, taking into consideration that other important factors may be involved, a reasonable period of years for repayment may be taken as the product of 40 years and the current construction cost index referred to 1940 as a base. For example, if the current cost index is 2.0 referred to the 1940 base, the guide would indicate an 80-year repayment period. If a particular investigation indicates that it would require more years to repay, then consideration should be given to terminating the investigation. However, this should be used only as a guide, since other factors may bear more weight in such a determination.

.3 The form of report to be submitted shall be the same as that for a planning report in which authorization is recommended, consistent with the adverse findings of the investigation. The reasons for not recommending authorization should be summarized clearly in the conclusions of the Regional Director's report. The recommendation should be a simple straightforward statement along this suggested pattern: FORM

"It is recommended that improvement of the _____ River Basin (or specific project or planning activity) for irrigation (or for irrigation and other purposes) as presented herein be not authorized at this time. It is recommended further that the question of authorization be left open for reconsideration at such time as the economic needs of the Nation, further information on the project, or other developments may justify such reconsideration."

ADEQUACY OF INFORMATION .4 It is possible that an unfavorable planning report may constitute the basis for future construction as a part of an unemployment relief program, or under other future conditions, without providing an opportunity for the Bureau to reconsider and to revise the report. Similarly, the Congress might, under certain conditions, authorize the construction of a project contrary to the Bureau's recommendations. Consequently, it is desirable that extreme care be taken so that the basic facts bearing on the feasibility or infeasibility of the project are clearly and accurately compiled and consistently presented in the planning report before it is submitted to the Commissioner. (See Part 2.)

PROCESSING ★.5 An unfavorable report is processed in the manner prescribed in Chapter 4.9.★

CHAP. 4.9 PROCESSING OF PLANNING REPORTS

.1 This chapter covers procedures for the processing of reports to insure all affected branches and staff offices and affected agencies a voice in matters which are their functional responsibility or interest and which may be affected by action taken as a result of a report, and to insure compliance with all procedures required by law or by the Department. SCOPE

.2 As a general policy, the initiation, preparation, and processing of project planning reports will be accomplished in such a manner as to allow all interested agencies full opportunity to review and comment on the proposed plans prior to submission of the report to Washington for action. It is a general policy to complete and process all planning reports as quickly and efficiently as practical after investigations are completed so that they may be submitted to the Congress in accordance with provisions of the Reclamation Laws for such action as may be necessary, and for printing as documents of the House or Senate. In cases where the Congress authorizes a project or unit prior to the formal submission to the Congress of planning report thereon, but subsequent to submission of the report to the affected states and the Secretary of the Army under provisions of the Flood Control Act of 1944, it is a general policy to complete the processing of the report and submit it to the Congress for information, record, and for printing, so that the printed report may be made available generally to all interested persons or agencies. If a project is authorized before a report reaches this stage of processing, file copies of the uncompleted report, with notations referring to the authorization, should be submitted to the Washington office as soon as possible for reference purposes. GENERAL POLICY

.3 Basin, subbasin, and project reports shall be prepared in conformance with Chapter 4.2. In general, reports shall be prepared as proposed reports of the Regional Director and circulated for review prior to the submittal of the signed report to the Commissioner. BASIN, SUBBASIN, & PROJECT REPORTS

.4 When a Regional Office is first assigned responsibility for a report on a project or improvement, a one-page Notice of Initiation of Investigation (Illustration 1) will be prepared, mimeographed, and given broad circulation by the Regional Director. The circulation of the Notices to Federal agencies will be made in accord with current policies and procedures of the Federal Inter-Agency River Basin Committee for the distribution and coordination of reports. ★Federal agencies not represented on the FIARBC which have related responsibilities in water resource development and utilization also should be furnished copies of the Notices.★ The Notice will indicate (1) the scope of the proposed investigation, (2) the nature of the problems which appear to be involved, and (3) any known contemplated or prospective solutions which will be explored. The Regional Director or his designated representative will contact corresponding Regional Offices of the other departments and agencies by mail, telephone, or in person and request an expression within a specified period as to what interests they may have in the proposed project or improvement and what pertinent data they may have or know about that can be made available, together with such comments and suggestions on these subjects as they may care to make. NOTICE OF INITIATION OF INVESTIGATION

.5 Ten additional copies each of the Notice of Initiation of Investigation will be furnished to the regional or field office concerned of the Fish and Wildlife Service, National Park Service, and the Bureau of Indian Affairs, which in turn, will furnish copies to organizations or others known to be interested or concerned. Such organizations include conservation groups which are not required by law to review reports and submit views and recommendations thereon. Organizations concerned with the functions ordinarily considered as falling within the field of activity of the Fish and Wildlife Service, the National Park Service, and the Bureau of Indian Affairs will therefore be urged to bring their interests and concerns to the attention of the Department through these agencies. CONSERVATION GROUPS

.6 As the plan which is to be incorporated in the Report of the Regional Director is being formulated, the Regional Director or his representative responsible for the report will from time to time contact and arrange for mutually CONFERENCES WITH OTHER AGENCIES

desirable conferences with the corresponding Regional Offices of other departments or agencies which have indicated an interest in the investigation in order to determine what pertinent data are in existence, arrange for the interchange of such data, arrange schedules for obtaining additional data without duplication of effort, interchange information, and discuss the proposed plan and report.

PUBLIC HEARINGS

.7 In the event that there are major conflicts of views among those interested or concerned in the proposed projects, or if the Bureau is requested by an affected state, an appropriate local interest, or any other agency of the Department to hold a public hearing, the Regional Director may direct that such a public hearing be held to solicit the views of all interested parties. Such hearings may be in addition to, or in lieu of, other means of soliciting the views of the various interests. The information and opinions obtained at such hearings should be considered in the preparation of the Report of the Regional Director. (See Chapter 6.1 for information on preparation of Notices of Public Hearings.)

PROPOSED REPORT OF REGIONAL DIRECTOR

.8 The proposed Report of the Regional Director (formerly called "Preliminary Draft of Report") on a basin, subbasin, or on a project should contain the Regional Director's report, including his tentative, unsigned recommendations, the substantiating report, and on the larger, more complicated projects, detailed appendixes. The substantiating report shall include the reports of other Department of the Interior agencies prepared at regional level. Comments at the regional level of other agencies ordinarily will be included in the ★substantiating materials.★ The appendixes are normally prepared as separate volumes, except in instances where they are not too voluminous, in which case they may be bound in the same volume with the Report of the Regional Director. In that case, the substantiating report, as such, may be eliminated.

Circulation For Review Outside Of Bureau

A. When the proposed Report of the Regional Director has been completed, and before submission to the Commissioner, it will be submitted to the regional offices of other Federal agencies that have a practical interest in the report, to officials of the affected states who have been designated to review the reports in accordance with provisions of the Flood Control Act of 1944 (58 Stat. 887) and Public Law 732 of the 79th Congress (60 Stat. 1080), and to other offices which have indicated an interest in the investigation. A reasonable period of time will be specified by the Regional Director within which to submit written comments on the report. Such comments, ★or digest thereof,★ will usually ★be included in the substantiating materials.★ When transmitting the proposed report for review, it may be indicated in the letter of transmittal that, when the report is completed and is approved by the Secretary, it will be sent officially to the Governors or other officials of the affected states and to the Secretary of the Army for their views and recommendations as required by the two cited acts.

Circulation For Review Within Bureau

B. Unless otherwise directed, the Regional Director shall send copies of each proposed report for comment as follows:

(1) To the Commissioner, attention 700, for distribution to branches and offices in Washington. 34 copies

(2) To Bureau offices outside of Washington:

Chief Engineer	6 copies
Chief, Hydrology Division, Branch of Project Planning	3 copies
Other Regional Directors concerned	3 copies

Two copies of all appendixes shall be submitted to the Commissioner, attention 700, at the time of submission of the proposed Report of the Regional Director. A copy of the water supply and related appendixes also shall be sent to the Chief, Hydrology Division, Branch of Project Planning, and a copy of the designs and estimates appendix shall be sent

to the Chief Engineer. Copies of the proposed reports may be furnished to interested Senators and Congressmen for their information at the discretion of the Regional Director.

C. In order that there will be no confusion between proposed reports which are circulated by the Regional Director to obtain comments, and the final reports submitted to the Commissioner for further action, these proposed reports shall be clearly marked on the cover and across the table of contents with stamped letters at least one-fourth inch high as follows: Stamp

PROPOSED REPORT
OF REGIONAL DIRECTOR
FOR OFFICIAL REVIEW ONLY
SUBJECT TO REVISION

When it is desired that an advance copy of a planning report be held in confidence, the phrase "For Administrative Use Only, Subject to Revision," may be used. The word "Confidential" shall be used on planning reports only when required by Security Regulations.

D. To facilitate substitution, removal, or addition of pages, proposed Reports of the Regional Director ★preferably should be reproduced★ and bound in loose leaf fashion suitably tied or bolted together. Reproduction & Binding

E. Each branch and office of the Bureau shall be responsible for reviewing the proposed reports, primarily with respect to the particular functions of the branch or office. Each branch and office head shall determine to what extent his comments should be restricted to his unit's functional field. The review by branches and offices will be coordinated by the Branch of Project Planning, which shall afford all branches and offices an opportunity to comment on the reports. Where special problems are involved, or when specifically requested by any of the branches or offices, a Bureau Clearance Conference (see Paragraph 4.9.9B(2)), may be held. Normally, it will not be necessary to hold a formal clearance conference, but comments will be transmitted formally or informally to the Branch of Project Planning, which Branch will be responsible for drafting the Commissioner's comments to the Regional Director. Written comments from offices located outside of Washington and from other Regional Directors shall be mailed directly to the Regional Director, with a copy to the Commissioner, attention 700, so that they can be considered along with the comments of the other branches and offices in formulating the Commissioner's comments. The proposed Reports of the Regional Directors shall be considered as to technical accuracy and adequacy, as well as with regard to Bureau policy. The Commissioner's comments to the Regional Director will endeavor to present suggestions to facilitate any necessary revision of his proposed report in order that it may be accepted by the Commissioner for further processing. The Commissioner's letter of comment shall indicate the number of copies of the final draft of the report which will be required by his office for use in final clearance and processing. Review Of Proposed Report Of Regional Director

★F. Reports, conclusions, and recommendations of the Fish and Wildlife Service and National Park Service concerning contemplated water development projects or proposals of the Bureau of Reclamation may be released to appropriate conservation organizations or to the general public after the Regional Director of the Bureau of Reclamation has had opportunity to review the reports of the Fish and Wildlife Service or National Park Service and, if possible, to reconcile differences, and when: Timing Conservation Releases

(1) The Regional Director of the Bureau of Reclamation has circulated his proposed report for review and comment among other regional offices and the proposed report is made available to those with a legitimate interest.

(2) Specific earlier approval is obtained from the Regional Director of the Bureau of Reclamation if release of reports or other information is desired prior to the date that is set forth in Subparagraph (1) above.★

REPORT OF REGIONAL DIRECTOR

.9 Upon receipt of the solicited comments on his proposed report, the Regional Director shall modify the report as necessary, giving due consideration to the functional comments from the branches and offices of the Commissioner, and to the extent he deems desirable, to the comments received from other sources. Reports or comments of other agencies shall be included in the substantiating report ★★★ as described in Paragraph 4.9.8A. The final draft of the report, including the Regional Director's signed report complete with recommendations and substantiating report, shall then be prepared and submitted to the Commissioner. The form of reproduction is specified in Subparagraph 4.9.8D. This report shall not be distributed outside of the Department as the official report of the Department until it has been approved by the Secretary.

Submittal Of Report Of Regional Director

A. The Regional Director shall submit the required number of copies of the report to the Commissioner, attention 700, for final clearance and processing. At the same time, the Regional Director shall send six copies direct to the Chief Engineer, and three copies direct to the Chief, Hydrology Division, Branch of Project Planning.

Clearance Within Commissioner's Office

B. Upon receipt of copies of reports, the Branch of Project Planning shall transmit copies to the heads of each of the branches and offices of the Commissioner and will set a date for the completion of the review. The Director, Branch of Project Planning, also will notify the offices outside of Washington of the date for completion of the review and submittal of comments.

Comments

(1) The branches outside of Washington shall transmit their comments on the report to the Commissioner, attention 700, with copies to the Regions involved, as far as possible in advance of the date established for the completion of the review. The branches and offices in Washington shall transmit their comments to the Director, Branch of Project Planning. Comments and suggestions on any phase of the report may be made by any branch or office, but in general should be limited to the functional concerns of the branch or office involved, and to matters of real importance. In addition to technical accuracy and adequacy, the review will be conducted with a view toward determining whether the report in its present form, or with minor changes, is in appropriate form and has desirable scope and content for the Commissioner to send it to the Secretary.

Revised Pages

(2) In general, any necessary modifications to the report will be made in the Commissioner's proposed report to the Secretary. If this might result in embarrassment to the Bureau, or in the event of obvious misstatements or errors, the Regional Director will be afforded an opportunity to revise his report by the substitution of revised pages. Whenever pages of any report are revised, the revision number shall be shown in the binding margin at the extreme lower left corner of the revised page. For instance, if a page is revised once it will be shown as Rev. No. 1. If it is again revised, it would be shown as Rev. No. 2, and so on. This will differentiate the revised page from the original page. If the comments received are of sufficient importance to warrant the return of the report to the Regional Director with comments and suggestions for further revision of the report, it will be so handled.

Bureau Clearance Conference

(3) For reports of major importance, or when major policy questions are involved, or in other cases where deemed advantageous, a Bureau Clearance Conference will be held to consider the report. The Director of the Branch of Project Planning shall set a date for the conference, and will notify the heads of each of the branches and staff offices. In addition to oral comments and suggestions, which are made at the

clearance conference, all major comments shall be presented in writing either in advance of, or at the clearance conference.

C. When circumstances warrant, the Commissioner or his designated representative may elect to establish a board of review (see Chapter 8.4 of Volume XVII) for any particular report, and charge that board with the responsibility of making recommendations to him concerning the action to be taken with respect to the plan or project. Board Of Review

.10 Upon approval of the Report of the Regional Director, the Director, Branch of Project Planning shall be responsible to the Commissioner for the preparation of a proposed Commissioner's report to the Secretary, based on and including the Report of the Regional Director. The proposed Commissioner's report shall then be cleared through appropriate Departmental channels and submitted to the Secretary for approval and adoption as his proposed report. In those cases where neither applicable law nor policy require that the views of any other Government agency or the views of any state be solicited, there would be no necessity for preparing a "proposed" report of the Commissioner. Rather, in such cases, a Commissioner's report would be cleared through appropriate Departmental channels and submitted to the Secretary for approval and adoption as his report. PROPOSED COMMISSIONER'S REPORT

.11 Upon approval and adoption of the Commissioner's proposed report by the Secretary, the Director, Branch of Project Planning shall prepare letters for the Commissioner transmitting the proposed report of the Secretary (including the Report of the Regional Director and substantiating report thereto), to the affected states, and to the Secretary of the Army, for their views and recommendations, when required in accordance with law. The following planning reports will be referred to the heads of other departments or agencies in Washington: PROPOSED SECRETARY'S REPORT--TRANSMITTAL TO REVIEWING AGENCIES

A. Reports required to be submitted to other departments or agencies in accordance with existing law.

B. Reports prepared prior to authorization (preauthorization) upon which there is lack of agreement at regional level.

C. Preauthorization reports upon which there has been agreement at regional level, but which are substantially changed in Washington, D. C., after their receipt from the originating Regional Office.

D. Definite ★Plan Reports★ when in the opinion of the Commissioner the comments or views of other departments or agencies are necessary or desirable.

.12 Following receipt of comments from the affected states, the Secretary of the Army, and Federal agencies, the Director, Branch of Project Planning shall draft a letter from the Commissioner to the Secretary, enclosing the Regional Director's report and the Secretary's proposed report, together with comments, if any, from the affected states, the Secretary of the Army, and representatives of other Federal agencies. The Commissioner's letter will include his recommendations for further Departmental action on the report. COMMISSIONER'S REPORT

.13 Upon approval of the Commissioner's letter by the Secretary, and adoption of the proposed report of the Secretary as the report of the Secretary (with or without modifications), this material (which will then include the comments of the states, the Secretary of the Army, and the interested agencies where these have been solicited, the proposed report of the Secretary, and the Regional Director's report, together with the substantiating report), will be transmitted by the Secretary as his report to the President through the Bureau of the Budget for the views of the Bureau of the Budget concerning the relation of proposed developments to the program of the President. SECRETARY'S REPORT--TRANSMITTAL TO THE PRESIDENT

.14 After receipt of the Bureau of the Budget's statement as to the relation of the proposals contained in the report to the program of the President, the Secretary will transmit the complete report to the Congress. TRANSMITTAL TO THE CONGRESS

SECRETARIAL OR CONGRESSIONAL AUTHORIZATION

.15 If the project meets the standards of feasibility prescribed by Section 9(a) of the Reclamation Project Act of 1939, and if no objections to the project have been raised by the affected states, or the Secretary of the Army where in appropriate cases their views have been solicited, transmittal of the report by the Secretary to the President and the Congress would authorize the project under the Reclamation Project Act of 1939. In other cases, including reports under special legislation, the Secretary will make appropriate recommendations to the Congress for action based on the findings as summarized in his report.

DISTRIBUTION DEFINITE PLAN REPORTS

.16 The distribution of Definite Plan Reports will be in accord with the instructions contained in Chapter 4.3.

RECONNAISSANCE REPORTS

.17 No specific processing of reconnaissance reports beyond the Regional Director's office is contemplated. Sufficient copies of reconnaissance reports shall be reproduced so that all branches and offices within the Regional Office that are concerned with the investigations program may be furnished copies, and that copies will be available for official files of the Bureau. In addition, 10 copies of reconnaissance reports approved by the Regional Director shall be transmitted to the Commissioner, attention 700. Four copies shall be sent to the Chief Engineer, and two copies to the Chief, Division of Hydrology, Branch of Project Planning.

REHABILITATION & FINANCIAL ADJUSTMENT REPORTS

.18 Processing of rehabilitation and financial adjustment reports on existing reclamation projects depends on the individual requirements in each case. Ordinarily, if such a report contains a proposal for authorization of additional works, it will be processed in the manner prescribed in this chapter for planning reports. Certain of these reports may be for informing the Regional Director, Commissioner, or the Congress of the circumstances that need attention in the rehabilitation and financial adjustment of existing works without containing recommendations for additional authorization. In such an event, the report may be used as justification for appropriations. The processing of such a report shall be determined by the Regional Director for his Region, and by the Commissioner for his office. Unless otherwise instructed, the Regional Director shall furnish 12 copies of each such report to the Commissioner, attention 700; four copies to the Chief Engineer; and two copies to the Chief, Division of Hydrology, Branch of Project Planning.

POWER PLANNING REPORTS

.19 The preparation of power planning reports will follow the procedure as set forth in Chapters 2.2, 2.3, and 2.4. Unless otherwise instructed, the Regional Director shall furnish 12 copies of each power planning report to the Commissioner, attention 700; four copies to the Chief Engineer; and two copies to the Chief, Division of Hydrology, Branch of Project Planning. When such a report is part of a multiple-purpose planning report, it will be processed as set forth hereinbefore.

SPECIAL-PURPOSE REPORTS

.20 Special-purpose reports cover such a wide variety of conditions that it is not possible to specify detailed procedures for their processing. (See Chapter 4.7.)

Criteria

A. The following general criteria are prescribed as a guide for action on the various types of reports. Any report which recommends authorization of project works, or major modifications of authorized project works shall be processed in accordance with the procedures set forth in Paragraphs 4.9.3 through 4.9.13 for basin, subbasin, and project reports. Any report which recommends a continuing program of investigations and reports on status of investigations shall be processed as specified in Chapter 4.4 for reconnaissance reports. Interim reports on project or basin investigations in most cases will be processed as basin, subbasin, or project reports.

Public Hearing Reports

B. To the extent deemed desirable by the Regional Director, public hearing reports shall be given wide distribution to the public and agencies which may be affected by the contemplated projects. Distribution shall include that specified in Chapter 6.1 for notices of public hearings. The Director, Branch of Project Planning, shall distribute copies to the other Department of the Interior agencies in Washington to the extent deemed desirable.

C. Market study reports may be included as an appendix to a basin, project, or subbasin report. However, in cases where wide interest is expected, 25 copies of the completed report shall be transmitted to the Commissioner, attention 700. Market Study Reports Other Than Power

D. Preliminary allocations reports for project, subbasin, and basin plans shall be included as a portion of the economic analysis of the substantiating reports. When revised allocations reports are required, the Regional Director shall transmit 25 copies to the Commissioner, attention 700. The Director, Branch of Project Planning, shall distribute copies to all affected branches and coordinate the review of the report. In the event that revisions of the Regional Director's report are desired, the Regional Director shall be informed and given an opportunity to revise his report. The Director, Branch of Project Planning, shall prepare the necessary documents for the Commissioner to transmit the report to the Secretary, and, where necessary, for the Secretary to transmit the report to the President and the Congress in accordance with the provisions of the Reclamation Project Act of 1939. The Regional Director shall also transmit four copies of the report to the Chief Engineer and two copies to the Chief, Division of Hydrology, Branch of Project Planning. Allocations Reports

E. Summarized data reports on units of authorized projects or units of projects recommended for authorization shall be processed as specified herein for definite plan reports. The summarized data reports will be submitted to the Commissioner with the final draft of the basin report. (See Paragraph 4.7.10.) Summarized Data Reports

C. Market study reports may be included as an appendix to a basin, project, or subbasin report. However, in cases where wide interest is expected, 25 copies of the completed report shall be transmitted to the Commissioner, attention 700. Market Study Reports Other Than Power

D. Preliminary allocations reports for project, subbasin, and basin plans shall be included as a portion of the economic analysis of the substantiating reports. When revised allocations reports are required, the Regional Director shall transmit 25 copies to the Commissioner, attention 700. The Director, Branch of Project Planning, shall distribute copies to all affected branches and coordinate the review of the report. In the event that revisions of the Regional Director's report are desired, the Regional Director shall be informed and given an opportunity to revise his report. The Director, Branch of Project Planning, shall prepare the necessary documents for the Commissioner to transmit the report to the Secretary, and, where necessary, for the Secretary to transmit the report to the President and the Congress in accordance with the provisions of the Reclamation Project Act of 1939. The Regional Director shall also transmit four copies of the report to the Chief Engineer and two copies to the Chief, Division of Hydrology, Branch of Project Planning. Allocations Reports

E. Summarized data reports on units of authorized projects or units of projects recommended for authorization shall be processed as specified herein for definite plan reports. The summarized data reports will be submitted to the Commissioner with the final draft of the basin report. (See Paragraph 4.7.10.) Summarized Data Reports

NOTICE OF INITIATION OF INVESTIGATION

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
NOTICE OF INITIATION OF INVESTIGATION

Name of Investigation: Kalispell Project, Montana1/
Location of investigation: Flathead County, western Montana, near Kalispell.

Date Investigation initiated: Sept. 1940 Probable date of completion June 30, 1949.

1. Scope of proposed investigation:

Determination of methods of furnishing a full water supply to 83,400 acres of arable dry land and a supplemental supply to 1,600 acres of inadequately irrigated land located in the general vicinity of Kalispell, Montana, along the Flathead River and tributaries, requires a study of alternate plans of development including pumping and gravity diversion as well as power development. A feasibility report is to be prepared.

2. Nature of problems involved:

Whether an all-gravity, all-pumping or combined gravity-pumping scheme will be most feasible. Possible drainage problems on low-lying lands. Flood control problems along the main river.

3. Prospective solutions which should be explored:

Alternate main canal locations and pumping plant locations. Possible storage and use of waters of Stillwater River to supply a portion of the project area.

Prepared by _____ Date _____ Transmitted by: _____ Date _____

_____ Signature _____ _____ Signature _____
Regional Director, Region I

1/ Former name: Kalispell Unit, Hungry Horse Project, Montana

CHAP. 4.10 EDITORIAL TECHNIQUES

.1 Drafting standards, duplicating processes, style standards, and techniques to be used in the preparation of planning reports, and in other documents and reports, are set forth in ★Chapter 1, Design Supplement No. 1 to Volume X and Volume XXI.★ This chapter supplements such standards, and in addition sets forth techniques required for effective preparation and duplication of planning reports. GENERAL

.2 A planning report shall be a concise and impartial presentation of the findings and conclusions of an investigation. The fact that major planning reports are intended for transmission to the Congress and may form the basis for testimony before the Bureau of the Budget and Committees of the Congress, as well as being the medium through which the general public may be advised of the results of an investigation, dictates the use of a literary style that not only presents engineering and economic facts, but is readable and understandable to both nontechnical and technical readers. LITERARY STYLE

.3 The report should be comprehensive, simple and clear, condensed to the essentials of the findings, logical in arrangement, free from discrepancies and ambiguities, and conclusive in tone, justifying the adequacy and the dependability of the findings. REQUIREMENTS

.4 Proper grouping of related facts and ideas is essential to an orderly presentation of the subject. Repetition should be avoided except as required for emphasis. The outlines presented in preceding chapters will assist the report writer in securing a logical arrangement and in maintaining continuity of thought. LOGICAL ARRANGEMENT

.5 Statements made in a report must be based on facts which can be verified. Discrepancies between text, tables, design drawings, and estimates cast doubt on the accuracy of the investigation, and should be avoided by careful review. ACCURACY

.6 The writer should avoid the too frequent use of "it is estimated" which suggests vagueness and tends to imply a lack of confidence in the investigation. This and similar phrases should be used only where necessary to express a reservation or where essential to an understanding of an idea. Expressions such as "it is assumed" and "for the purposes of this report" should rarely be used. EXPLICIT LANGUAGE

.7 Abbreviations should appear only in tabulations and similar places. The abbreviations used should conform to those prescribed in the Government Printing Office Style Manual. ABBREVIATIONS

.8 Except where required by law or executive authority, the use of the abbreviation "U.S." or the words "United States" will be omitted before titles of bureaus, offices, services, divisions, institutions and other units, or officials and employees of the Department of the Interior. When Department of the Interior is used in titles, it shall be referred to as the United States Department of the Interior with the "United States" spelled out. Similar usage should be followed in titles of agencies of other departments of the Government. (See Chapter ★9.1★ of Volume I.) USE OF "UNITED STATES"

.9 It is mandatory that geographical names designated by the United States Department of the Interior, Board on Geographical Names, be used in all reports, publications, and on all maps and charts. Approved names may be obtained from publications of the Board on Geographical Names, which are available at practically all United States Government Depository Libraries, and in each Regional Office. When there is any doubt as to the use of names in reports or on maps, the Commissioner's Office, code ★240★, should be consulted. (See Part 3 for the naming of geographical and construction features of Bureau of Reclamation projects.) GEOGRAPHICAL NAMES

.10 Estimate totals and similar figures that are inherently approximate should be "rounded off" to avoid a misleading appearance of a nonexistent degree of accuracy and to simplify citation of the figures. For instance, if several items in an estimate of cost total $12,364,235, and the main item, the spillway, is ESTIMATE FIGURES

estimated to cost $6,000,000 and is probably accurate within $100,000, then the total estimate should be rounded to, say, $12,360,000, and preferably to $12,400,000. The estimate of $12,364,235 certainly would imply an accuracy far in excess of reality, and should not be used, even though one small item, say, the cost of fish and wildlife facilities, was estimated to be $4,235.

FORMAT .11 All planning reports shall be prepared according to the standard format, in the interest of uniformity and for convenience in reference. ★(See Specialist Supplement No. 1 to Volume XXI.)★

PAPER & REPRODUCTION .12 The original shall be typed on standard weight, 8-inch by 10-1/2-inch white paper, and carbon copies shall be on thin opaque paper, except in cases where a large number of copies are desired. When a large number of copies are desired the report will be mimeographed, multilithed, or printed, as circumstances warrant.

PARAGRAPH NUMBERING .13 Each paragraph in the Regional Director's signed report shall be numbered consecutively, without regard to the insertion of necessary or desirable subheadings. This does not apply to the substantiating report of basin, subbasin, and project reports, or other planning reports in which the paragraphs are not numbered.

TITLE & INTRODUCTORY PAGES .14 Each report should begin with a title page; a frontispiece consisting of an appropriate drawing, photograph, or location map; a table of contents listing each chapter and topic heading, properly indented, with its page number; and a list of the illustrations and page position numbers contained in the report. In the case of an exceptionally brief special-purpose report those introductory pages which are not necessary to convenient references may be omitted. Any large report that may later be printed should include an index.

BINDING .15 Binding shall be as prescribed in Chapter 4.9.

MAPS .16 Maps, drawings, and charts should be bound in the report at appropriate locations. Drawings and charts are necessary to a clear presentation of a plan. Usually a location map, a general map, a water-supply operation diagram, and preliminary design drawings of major project features are needed for a project report. Other drawings and charts should be included as required. To the extent possible, illustrative material should be prepared originally in proportions that will reduce to 7-1/4 inches wide and 9-1/2 inches long. The correct scaling of width is particularly necessary in order to avoid having to turn the book sideways in order to read the illustration. Plates and negatives of maps--colored maps in particular--should not be destroyed, as they may be used later to supply maps for a printed edition.

PHOTOGRAPHS .17 Photographs should ordinarily be omitted from the Report of the Regional Director, since the report is often published as a public document and special authorization is required for reproduction of photographs in a printed report. However, suitable photographs may be used profitably in illustration of the substantiating material and other planning reports.

TABLES .18 A tabular presentation is frequently found to be the most effective means of presenting basic data. Tables should be used as needed or desirable but use of many tables in a Regional Director's report should be avoided. Long tables should appear in the appendixes or substantiating material.

REPORT NUMBERING .19 ★Planning Reports should not be numbered.★

RECLAMATION LAWS .20 The planning engineer and the report writer must be familiar with the basic Reclamation Laws. A copy of "Federal Reclamation Laws, Annotated April 1943," and subsequent supplements, are an invaluable reference work.

PREPARATION FOR PRINTING .21 Material for certain reports that are ordered to be published shall be furnished to the Chief Publications Officer in the following form when requested by the Commissioner:

The preliminary draft of a report would contain zero as the revision number. As an example, the preliminary draft of the Lahontan Basin report will show the following on the cover and on the title sheet:

Project Planning Report No. 4-6.0-0

and the first revision thereof would be shown as:

Project Planning Report No. 4-6.0-1

and so on.

REPORTS INVOLVING TWO REGIONS

A. The Colorado River Basin report, as an example, involved two regions and two field account numbers and was numbered 34-8-1. This number indicates that the report deals with areas in Regions 3 and 4. The two basins 8a and 8b, upper and lower Colorado River, respectively, are designated by the field account number 8, although separate accounts will still be maintained for basins 8a and 8b as is now being done. The first revision is indicated by number 1.

SUBBASINS

B. Where subbasins carry the same field account number as the major basin, such as the Virgin and Little Colorado Basins in the Lower Colorado Basin, new field account numbers to identify such subbasins should be assigned by the Regional Directors. As an example, the Virgin River Basin has been assigned the field account number 8b.01, and the Little Colorado River Basin number 8b.02.

TRANS-BASIN DIVERSIONS

C. Reports of projects which involve transbasin diversions should be numbered to show the field account number indicative of the basin from which the project water supply is initially diverted.

RECLAMATION LAWS

.20 The planning engineer and the report writer must be familiar with the basic Reclamation Laws. A copy of "Federal Reclamation Laws, Annotated April 1943," and subsequent supplements, are an invaluable reference work.

PREPARATION FOR PRINTING

.21 Material for certain reports that are ordered to be published shall be furnished to the Chief Publications Officer in the following form when requested by the Commissioner:

A. Required number of copies of the report shall be furnished by the Director, Branch of Project Planning.

B. Originals of all illustrative materials shall be shipped flat, not folded, in strong containers to prevent crushing. These originals shall be clearly marked on wrappings to show their place in the book, i.e., "Figure 1, follows page 32," "Map of the Columbia Basin, page 117," etc.

C. Two contact prints of each photograph shall be submitted.

D. Illustrative materials shall be drawn on a scale suitable for reduction, as outlined in Paragraph 4.10.16.

E. When quantities of maps are printed in the field for inclusion in the printed report, these shall be shipped to a point designated by the Chief Publications Officer. Each title shall be wrapped separate from all others, i.e., California maps separate from all others, Arizona maps separate from all others, etc. For shipping convenience, there may be several packages of the same title. Each package shall be clearly marked to show which map the package contains and how many copies are enclosed.

DISPLAY CHARTS

.22 Presentations of basin plans and projects to Committees of the Congress, the Bureau of the Budget, and others are implemented by the use of suitable wall charts depicting the major features of the basin or project plan. Such

wall charts shall be prepared separately from the report and submitted by the Regional Director at the time of transmission in final form of his report on a basin or project, or immediately thereafter. The following guides should be followed in preparing display charts:

COVERAGE

A. The chart or map shall be drawn to show simply and clearly the principal features of the basin or project plan and the location of the basin or project with respect to widely known geographical points such as state boundaries and cities. If necessary to show geographical location, a small and very simple locality guide may be added. Extraneous and confusing details must not be shown, and decorations are prohibited.

SIZE

B. The chart should be prepared on medium-weight detail paper, or equivalent, so that wood moldings may be added in the Commissioner's office to the top and bottom edges of the map to permit hanging for display. The maximum size should be limited to 5 feet by 7 feet, with either dimension horizontal depending on the shape of the project area, but a lesser size should be used if that is possible without crowding and loss of clarity.

DETAIL

C. Poster technique should be used and the chart should be intelligible to the average reader from a distance of 40 feet although it may not be possible to distinguish all the minor features at that distance. For easy reading, the minimum height of lettering should be 3/4 inch, although 1/2-inch lettering will be satisfactory for minor features if necessary to avoid crowding and loss of clarity of the main features. Names of Reclamation projects or principal units should be the largest and boldest used on the chart, with the exception of the title lettering, and should be done in black. Names of rivers, lakes, political divisions, and similar items may be done in blue, gray, or color other than black.

SYMBOLS

D. The following color guides should be used in conjunction with standard symbols for the features illustrated:

Irrigated areas in green
Irrigable areas in yellow
Existing streams, reservoirs and canals in blue (shades may be varied to distinguish between features)
Proposed reservoirs in red, with heavy black shoreline and dam
Proposed canals and conduits in red
Existing power features in black; proposed power features in red
Political boundaries and towns should be in black, thin line.

The selection of colors should be based on the use of shades clearly visible from the specified distance of 40 feet. Particular attention should be given to the shade of yellow used, as many shades of this color fade out under artificial light.

TITLE

E. The chart should carry an appropriate title consisting of the following:

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
(NAME OF THE BASIN OR PROJECT)

ORIENTATION

F. The map should be so oriented that north is to the top or left edge of the chart, if possible. A north arrow should be shown. A simple bar scale should be used to indicate the basic scale.

DISPLAY PHOTOGRAPHS

.23 Presentations to the Bureau of the Budget and to the Congress can also be implemented by the use of well-chosen illustrative photographs. Contact prints of selected scenes to illustrate particular features of a plan should be submitted with the wall chart, if available. A request will be made by the Commissioner's office for adequate enlargements of those photographs selected for use.

PREPARATION FOR PRINTING (Cont.)

A. Required number of copies of the report shall be furnished by the Director, Branch of Project Planning.

B. Originals of all illustrative materials shall be shipped flat, not folded, in strong containers to prevent crushing. These originals shall be clearly marked on wrappings to show their place in the book, i.e., "Figure 1, follows page 32," "Map of the Columbia Basin, page 117," etc.

C. Two contact prints of each photograph shall be submitted.

D. Illustrative materials shall be drawn on a scale suitable for reduction, as outlined in Paragraph 4.10.16.

E. When quantities of maps are printed in the field for inclusion in the printed report, these shall be shipped to a point designated by the Chief Publications Officer. Each title shall be wrapped separate from all others, i.e., California maps separate from all others, Arizona maps separate from all others, etc. For shipping convenience, there may be several packages of the same title. Each package shall be clearly marked to show which map the package contains and how many copies are enclosed.

DISPLAY CHARTS

.22 Presentations of basin plans and projects to Committees of the Congress, the Bureau of the Budget, and others are implemented by the use of suitable wall charts depicting the major features of the basin or project plan. Such wall charts shall be prepared separately from the report and submitted by the Regional Director at the time of transmission in final form of his report on a basin or project, or immediately thereafter. The guides to be followed in preparing display charts are outlined in Chapter 6.2 of Volume VIII.

DISPLAY PHOTOGRAPHS

.23 Presentations to the Bureau of the Budget and to the Congress can also be implemented by the use of well-chosen illustrative photographs. Contact prints of selected scenes to illustrate particular features of a plan should be submitted with the wall chart, if available. A request will be made by the Commissioner's Office for adequate enlargements of those photographs selected for use.

Interior - Reclamation - Denver, Colo.

.24 Charts to accompany basin and project reports should not be confused with budget display charts, which will be requested separately by the Commissioner's office when required and which are designed to present data in support of budget items. BUDGET DISPLAY CHARTS

CHAP. 5.1 REVIEW OF REPORTS OF OTHER AGENCIES

SCOPE

.1 Reports of other agencies that are to be reviewed by the Bureau of Reclamation consist of:

A. Reports of the Corps of Engineers, transmitted pursuant to the requirements of Flood Control and Rivers and Harbors Legislation.

B. Reports of other agencies of the Department of the Interior which are transmitted by the Water Resources Subcommittee of the Departmental Program Committee for the information of the Bureau or for inclusion in basin or project reports.

C. Reports of the Departments of Agriculture and Commerce, Federal Power Commission, or other members of the Federal Inter-agency River Basin Committee which may be referred to the Departmental representative for comment by the Bureau.

D. Requests made by the Federal Power Commission for the views of the Department of the Interior on applications for licenses filed with the Commission.

REPORTS OF THE CORPS OF ENGINEERS

.2 In accordance with the policies of Congress, as expressed in Section 1 of the Flood Control Act of 1944 (58 Stat. 887) and repeated in the River and Harbor Act of 1945 (59 Stat. 10) (see Part 1 of this Volume) and retained in subsequent River and Harbors and Flood Control Legislation; the Chief of Engineers, Department of the Army, will transmit copies of his proposed reports on water resources development, using or controlling waters which rise in whole or in part west of the ninety-seventh meridian, to the Secretary of the Interior. The Secretary of the Interior may submit his written views to the Chief of Engineers within 90 days of receipt of the proposed report for transmittal by the Secretary of the Army to the Congress, along with the proposed report and the views and recommendations of the affected states.

COMMENTS OF CORPS OF ENGINEER REPORTS

.3 The written views of the Secretary of the Interior will be prepared by the Water Resources Subcommittee of the Departmental Program Committee. To obtain the views of the Bureau of Reclamation, the Water Resources Subcommittee will transmit copies of the proposed reports to the Bureau of Reclamation. The Director of the Branch of Project Planning will be responsible for obtaining the views of the Regional Director having jurisdiction over the locality involved in the report, and the other branches and offices of the Bureau in the Office of the Commissioner. Where interests of the Bureau of Reclamation are obviously not involved, the views of the other branches and offices need not be obtained, but in all cases a copy of the report shall be referred to the appropriate Regional Director for his comments. Comments shall, in general, be restricted to matters which affect or concern the Bureau of Reclamation.

TRANSMITTAL OF BUREAU COMMENTS

.4 Upon receipt of the views and comments of all affected regions, branches, and offices of the Bureau, the Director, Branch of Project Planning will prepare the comments of the Bureau of Reclamation for transmittal by the Commissioner to the Water Resources Subcommittee. Sufficient time should be allowed for the Secretary's letter of comment to be dispatched well in advance of the expiration of the statutory 90-day period.

REPORTS OF OTHER INTERIOR AGENCIES

.5 Reports of other agencies of the Department of the Interior involving the control or use of water in the West will be transmitted to the Bureau of Reclamation by the Water Resources Subcommittee, for information, for comments, or for inclusion in a basin or project report which is being prepared by the Bureau. The Director of the Branch of Project Planning will be responsible for bringing these reports to the attention of the appropriate Regional Directors and all other branches and offices of the Bureau that are affected. In cases where comments are requested, or are deemed to be necessary, they will be prepared by the Director, Branch of Project Planning, taking into consideration the views and comments of the Regional Director

involved and of the other affected branches and offices, and will be transmitted by the Bureau's representative on the Water Resources Subcommittee to the chairman of that Committee. Reports that are to be included in basin reports will normally be transmitted from the originating agency directly to the Regional Director who is preparing the basin or project report. If these reports are transmitted to the Bureau through the Water Resources Subcommittee, the Director, Branch of Project Planning, will transmit copies of the report to the Regional Director.

FEDERAL INTER-AGENCY RIVER BASIN COMMITTEE REPORTS

.6 Reports on multiple-purpose projects of the Department of Agriculture, Federal Power Commission, Department of Commerce, and other agency members of the Federal Inter-agency River Basin Committee transmitted to the Departmental representative and referred to the Bureau of Reclamation for comments shall be referred to the Director, Branch of Project Planning, who will be responsible for bringing these reports to the attention of the appropriate Regional Directors and all other affected branches and offices of the Bureau. Upon receipt of the views and comments of the affected Regional and Branch Directors, the Director, Branch of Project Planning, will prepare the comments for transmittal by the Commissioner to the Departmental representative.

FEDERAL POWER COMMISSION REFERRALS OF POWER LICENSE APPLICATIONS

.7 According to Secretarial Order 2391, the Chairman of the Water Resources Subcommittee of the Program Committee shall be responsible for the preparation and submission to the Secretary of responses to requests made by the Federal Power Commission for the views of the Department of the Interior on applications for licenses filed with the Federal Power Commission. The Chairman, or Executive Secretary, of the Water Resources Subcommittee refers such license applications to members of the Water Resources Subcommittee. The representative of the Bureau of Reclamation on the Water Resourses Subcommittee shall be responsible for bringing these referrals to the attention of the appropriate Regional and Branch Directors and all other affected offices of the Bureau. Upon receipt of the views and comments of the affected Regional and Branch Directors, the representative of the Bureau of Reclamation on the Water Resources Subcommittee will prepare the comments of the Bureau of Reclamation for transmittal by the Commissioner to the Chairman of the Water Resources Subcommittee.

Vol. III 5.2.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

MANUAL

VOLUME III

PART 5: STORAGE DAMS
CHAPTER 2: GRAVITY DAMS

DESIGN AND CONSTRUCTION HANDBOOK

Preliminary Outline

VOLUME III--DESIGN AND CONSTRUCTION HANDBOOK

Part 1. Introduction, Functions, Organization and Contacts

Chapter 1.1 Introduction
1.2 Functions and Organization
1.3 Contacts with Other Agencies

Part 2. Drawings, Specifications, Contracts, Reports, Correspondence

Chapter 2.1 Drawings, Maps, Reproductions, and Photographs
2.2 Estimates and Specifications
2.3 Contracts
2.4 Reports and Correspondence
2.5 Engineering Files

Part 3. Investigations, Materials Engineering, and Design Studies

Chapter 3.1 Final Surveys
3.2 Engineering Geology, Materials Engineering, and Hydraulic Laboratory Studies
3.3 Library Research
3.4 Technical Engineering Studies

Part 4. Structural Design Procedure, Standards, and Data

Chapter 4.1 General Structural Design Procedure and Standards
4.2 Concrete Building Design Standards
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Part 5. Storage Dams

Chapter 5.1 Preliminary Design Considerations
✓5.2 Gravity Dams
5.3 Arch Dams
✓5.4 Buttress Dams
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5.6 Spillways and Outlet Works

Part 6. Power Systems, Pumping Plants, and Appurtenances

Chapter 6.1 Turbines and Pumps
6.2 Hydraulic Conduits and Miscellaneous Related Utilities
6.3 Hydraulic Valves and Gates and Miscellaneous Mechanical Equipment
6.4 General Arrangment of Power Plants
6.5 Electrical Machinery and Accessories
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Part 8. Construction Facilities

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Part 9. Construction Engineering

Chapter 9.1 Construction Engineering Division
9.2 Construction Schedules and Cost Control
9.3 Contract Adjustments
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9.5 Labor and Wages
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Reclamation Manual

VOLUME III--DESIGN AND CONSTRUCTION

PART 5--STORAGE DAMS

CHAPTER 2--GRAVITY DAMS

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.1 A gravity dam is a solid concrete or masonry structure so designed and shaped that its weight is sufficient to insure stability against the effect of all imposed forces. The complete design of the dam includes not only the determination of the most efficient and economical proportions of the main water-impounding structure, but also the determination of the most suitable appurtenant structures for the release, control, and use of the impounded water consistent with the purpose or function of the project. DEFINITION

.2 The cross-section of the dam is obtained essentially by a method of trial. Several trial sections, the number required depending upon the experience of the designer, are subjected to the methods of analysis described later in this Chapter until a section is obtained which is practical and satisfies all the design requirements. The various factors considered during the design procedure may be grouped as follows: design assumptions, forces acting on the structure, requirements for stability, and, secondary effects due to elastic deformations of the structure and the yielding of the foundation. DESIGN CONSIDERATIONS

A. The basic assumptions involved in the design of gravity dams are listed and discussed in the preceding Chapter. Where an actual condition is not in agreement with an assumption, an effort is made to correct the condition, or the design of the structure or method of construction is so performed as to counteract the condition or otherwise to bring the structure within safety requirements. For instance, if the foundation contains open seams and fissures, it may not properly be assumed to be uniformly elastic and homogeneous unless suitable measures are taken, as by grouting the foundation, to produce an essentially homogeneous condition; or the dam may not be considered to be monolithic until the contraction joints and construction slots have been grouted. BASIC ASSUMPTIONS

B. The forces which must be considered in the design of gravity dams are those due to reservoir water pressure, tailwater pressure, uplift pressure, silt pressure, ice pressure, weight of the structure, reaction of the foundation, and earthquake effects. Methods of analyzing the effects of these forces are discussed later in this Chapter. EXTERNAL FORCES

C. The dam is considered stable when the induced stresses are within the design limits and when the weight is sufficient to prevent overturning and to resist all tendencies toward sliding on a horizontal plane. A more detailed discussion of stability requirements STABILITY REQUIREMENTS

(.2C) and their effect upon the analysis and design of the structure is given in later paragraphs on structural analysis.

ELASTIC PROPERTIES

D. The simple gravity analysis of a dam assumes the structure to be composed of a series of vertical independent adjoining unit cantilevers. However, the dam is usually so constructed that its action will be more nearly like that of a monolith. Furthermore, the foundation and the concrete mass are composed of materials which react to stress conditions essentially in accordance with theories for elastic materials. The elastic deformations and accompanying stress conditions in a unit cantilever, therefore, are influenced by the magnitude of similar conditions produced in the adjoining cantilever. In a complete analysis of the dam, therefore, the designer should consider the elastic properties of the concrete and foundation and should determine the state of stress in the three orthogonal planes passing through the point in question. The method of analysis considering the structure to be composed of three-dimensional elements is discussed in the latter part of this Chapter.

PRELIMINARY DESIGN

.3 As discussed in the preceding Chapter, preliminary designs are prepared primarily to determine the feasibility of a project and are based upon the desired functional requirements of the project and the site conditions determined by the preliminary field investigations. Since time and funds for field investigations are usually limited during the planning stage, preliminary designs are developed only to that extent which enable the determination of an adequate estimate of cost and the preparation of a general drawing of the dam and appurtenant features. Preliminary design may be expedited by adopting, as a trial dam, the section of some previously designed dam of similar proportions which is known to satisfy design requirements.

FINAL DESIGN

.4 Final designs studies are carried out subsequent to authorization of funds for construction. These studies include all changes in the requirements or objectives of the project plan and include a more thorough and detailed analysis of all features. The resulting final design will indicate the most suitable and economic proportions of the dam and appurtenant features and will include sufficient design drawings of all details required for the preparation of specifications and plans for construction. The procedures for design and analysis of the various features are discussed in the following paragraphs.

SPECIFICATION DESIGN

.5 In order that detailed estimates of cost of construction can be made by engineers and contractors and to insure

(.5) that the structure will be built in accordance with approved procedures, sufficient detailed information pertinent to the design and construction of the structure must be prescribed. This information is published in the form of specifications and specification drawings which include necessary details of the design of the main structure and its appurtenances, data pertinent to the geographical location of the construction site, requirements governing types and qualities of materials used, and provisions governing method of construction, workmanship, wage rates and conditions governing employment of labor, bonds to be furnished by contractor, payments for work, and legal and administrative provisions covering conduct of work called for by the contract. In the preparation of the specification drawings, general procedures are followed with respect to the sequence of drawings and the details shown; the amount of detail depending upon the complexity of the structure. Data required for preparation of designs are obtained from the field and from the various divisions and branches of the Bureau. The following paragraphs, applicable to the design and construction of a concrete gravity dam, describe elements which must be considered in preparation of the drawings and in determination of requirements of the General Specifications. The order in which the elements are discussed follows in general the order in which applicable drawings appear in the specifications.

SPECIFICATION DESIGN (CONT.)

.6 The location map will show the location of the construction site, main highways and access roads to the site, railroads, powerlines, rivers, cities and towns, Government camp, sand and gravel deposits, and many other related features. The total area covered should be large enough so that a mental picture can be formed of the influence of the above features on construction activities. The scale chosen for this map should be suitable for determination of road distances by direct scaling without appreciable error. On the same drawing there will be included an index map to show the location of the construction site with respect to state boundaries, large cities, and rail centers.

LOCATION MAP

.7 A hydrograph is a plot of the rate of streamflow against time. When such a plot is carried over a number of years, an estimate can be made of the probable frequency of normal peak flows and floods and the time of year they are likely to occur. This information is of importance to the contractor. He is then able to estimate the probable amount of flow during the construction period. This will have a direct bearing on the diversion facilities which must be provided, water load on the structure

HYDROGRAPHS

(.7) during construction, etc. For these reasons, hydrographs for each year of available record will be included in the specification drawings.

PREPARATION OF HYDROGRAPHS

In preparing hydrographs, the rate of flow is usually plotted in mean daily second-feet for each day of the month for each year of record. The scale chosen will be such that all the yearly graphs can be included on one drawing. Important data such as drainage area at the gaging station, distance from the gage to the construction site, additional drainage area included between these points, and amount of regulation offered by any upstream hydraulic structure will be included in notes on the drawing. All computations and compilation of data necessary to construct the hydrographs are made by the Hydrology Division of the Branch of Project Planning. Detailed information as to method of obtaining streamflow data is given in Chapter 2.5 of the Project Planning Handbook. An example of a specification drawing of hydrographs is given in Figure 1.

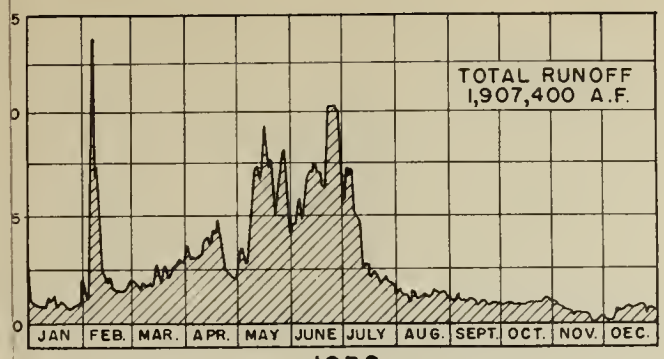
RESERVOIR AREA TOPOGRAPHY

.8 Topography of the reservoir area may be included in the specifications in order to show the extent of the area submerged by the reservoir and the location of any required saddle dams. This drawing may also be useful to the contractor for plotting submerged area during construction of the dam, likely locations for depositing excess material of excavation, and for planning access roads to these locations and to the base of the canyon at the damsite. Data for the preparation of the topography drawing are obtained by the field organization and the scale used is usually such that the entire area may be shown on one sheet.

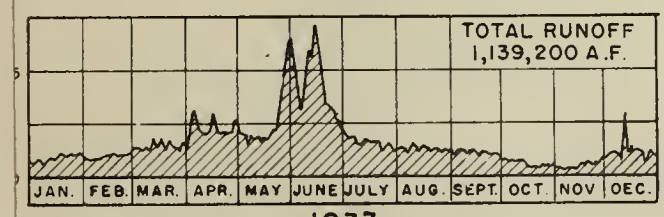
TOPOGRAPHY OF DAMSITE

.9 Based on survey data, a contour map of the construction site is prepared to a scale suitable for fairly accurate layout work. The contour interval used is usually 5 feet. The horizontal and vertical control systems will be shown by plotting the rectangular coordinate system, benchmarks (noting elevations), baseline, and stationing of control points. In order to show the relationship of the structure to the existing topography, the general outline and main features, such as the axis, intersection of base with assumed foundation, and any tunnels, flumes, or canals forming part of the completed project or which are to be used temporarily for river diversion purposes, will be indicated by dotted lines. The axis of the dam will be stationed

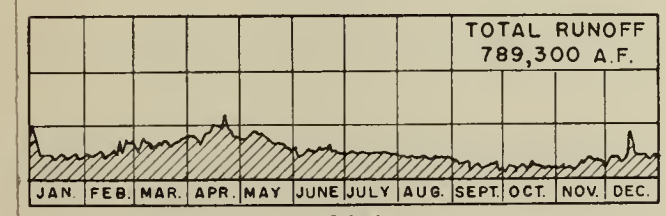
FIG. 1 par. 5.2.7



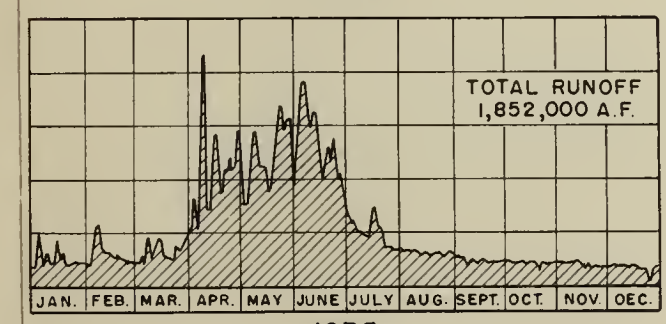
1932



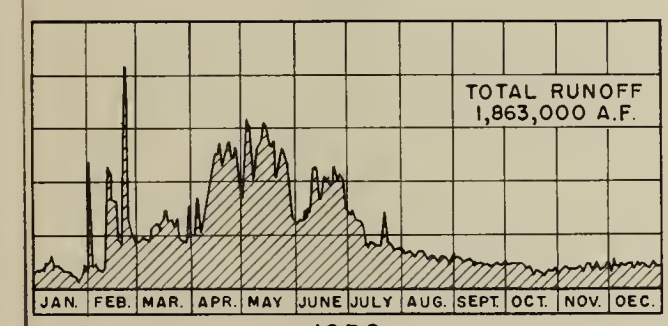
1933



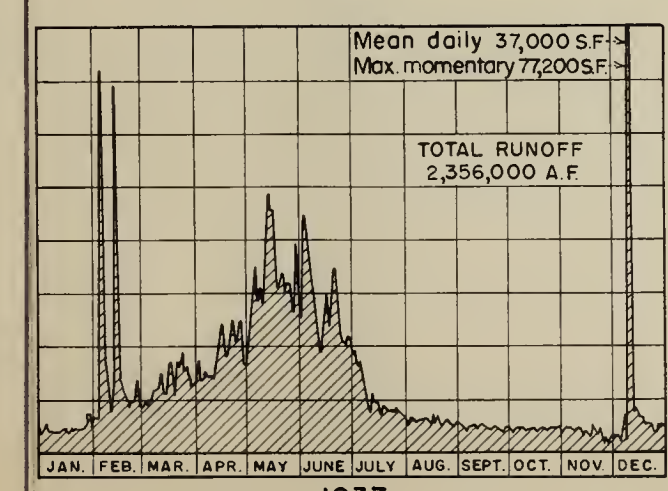
1934



1935

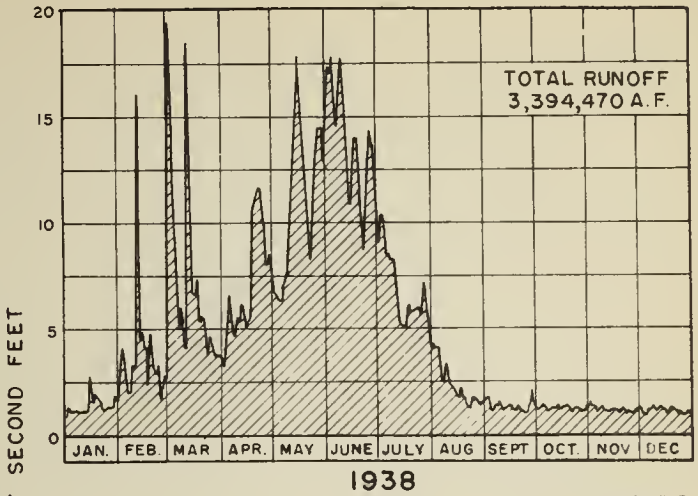


1936

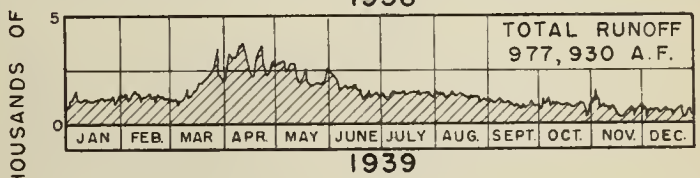


1937

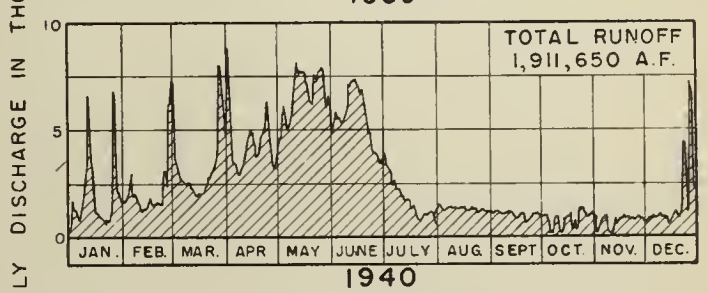
MEAN DAILY DISCHARGE IN THOUSANDS OF SECOND FEET



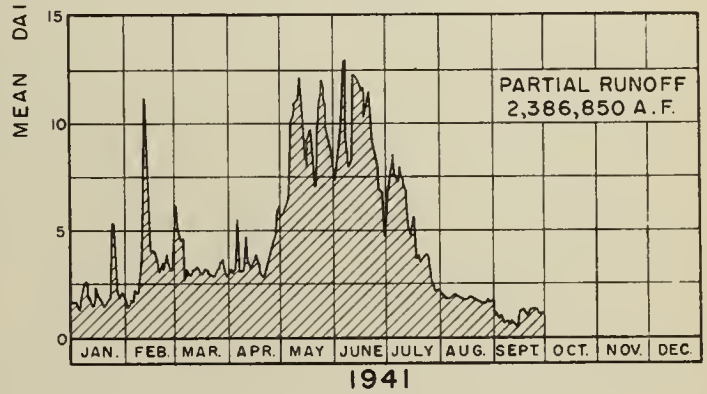
1938



1939



1940



1941

NOTES

Gaging station located about one mile upstream from Friant damsite. No important tributaries enter river between gaging station and damsite.

Drainage area 1650 square miles.

Flow is partially regulated by upstream reservoirs and power plants.

Total capacity of constructed upstream reservoirs as follows.

1910 -	45,000	acre feet
1917 -	134,000	acre feet
1920 -	139,000	acre feet
1926 -	204,000	acre feet
1927 -	339,000	acre feet

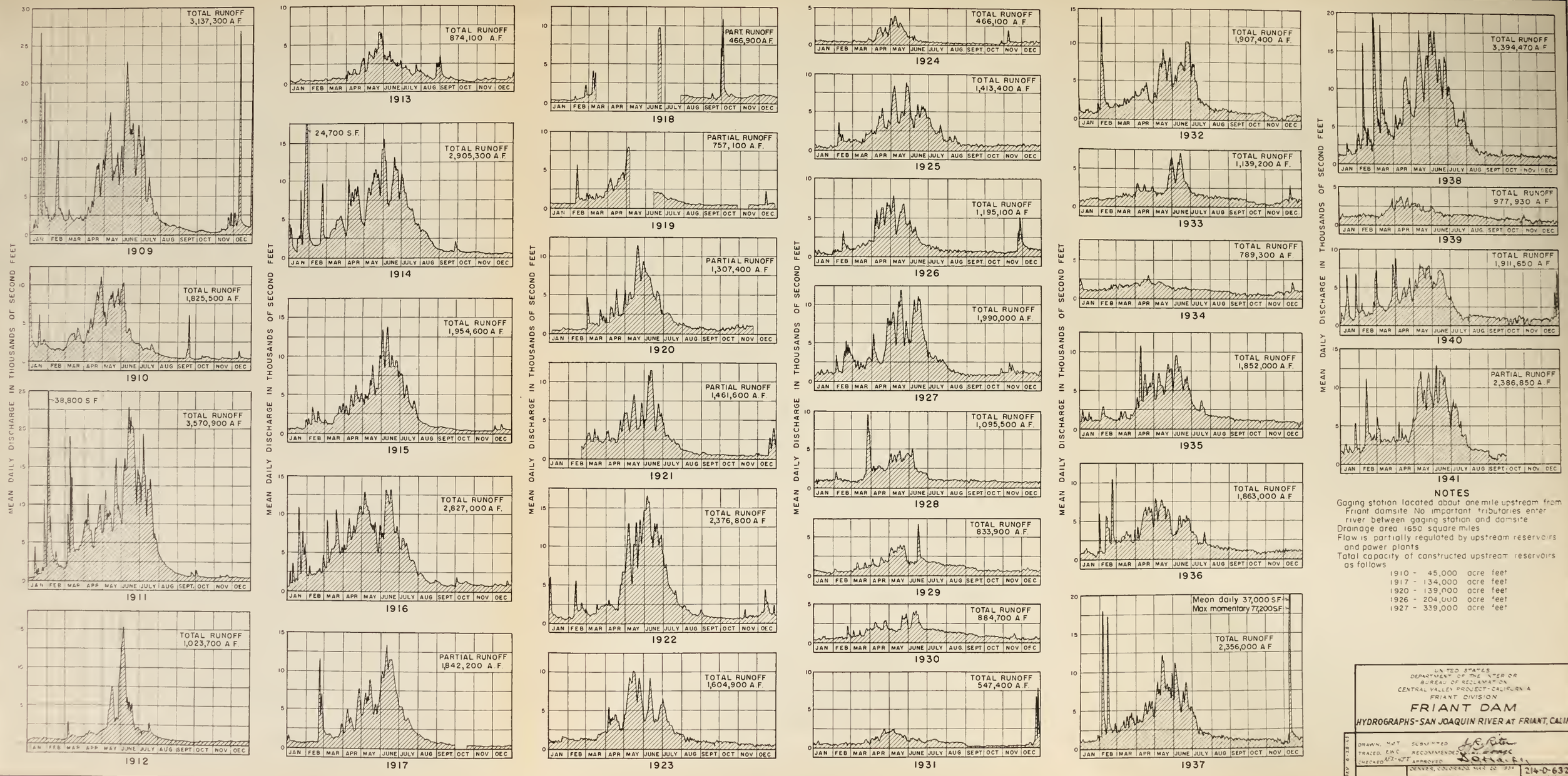
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT - CALIFORNIA
FRIANT DIVISION

FRIANT DAM

HYDROGRAPHS - SAN JOAQUIN RIVER AT FRIANT, CALIF.

DRAWN H.J.T. SUBMITTED J. R. Ritter
TRACED E.W.C. RECOMMENDED L. L. George
CHECKED A.F.T.-H.J.T. APPROVED [illegible]
DENVER, COLORADO, MAR. 20, 1939
214-D-632
REV. 6-28-43

FIG. 1 par. 5.2.7



NOTES

Gaging station located about one mile upstream from Friant damsite. No important tributaries enter river between gaging station and damsite.
Drainage area 1650 square miles.
Flow is partially regulated by upstream reservoirs and power plants.
Total capacity of constructed upstream reservoirs as follows:

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1926 - 204,000 acre feet
1927 - 339,000 acre feet

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT-CALIFORNIA
FRIANT DIVISION

FRIANT DAM

HYDROGRAPHS-SAN JOAQUIN RIVER AT FRIANT, CALIF.

DRAWN: HJT SUBMITTED: J. E. Riter
TRACED: EWC RECOMMENDED: [illegible]
CHECKED: [illegible] APPROVED: [illegible]
DENVER, COLORADO MAR 20 1934
214-D-632

FIG. 2 par. 5.2.9

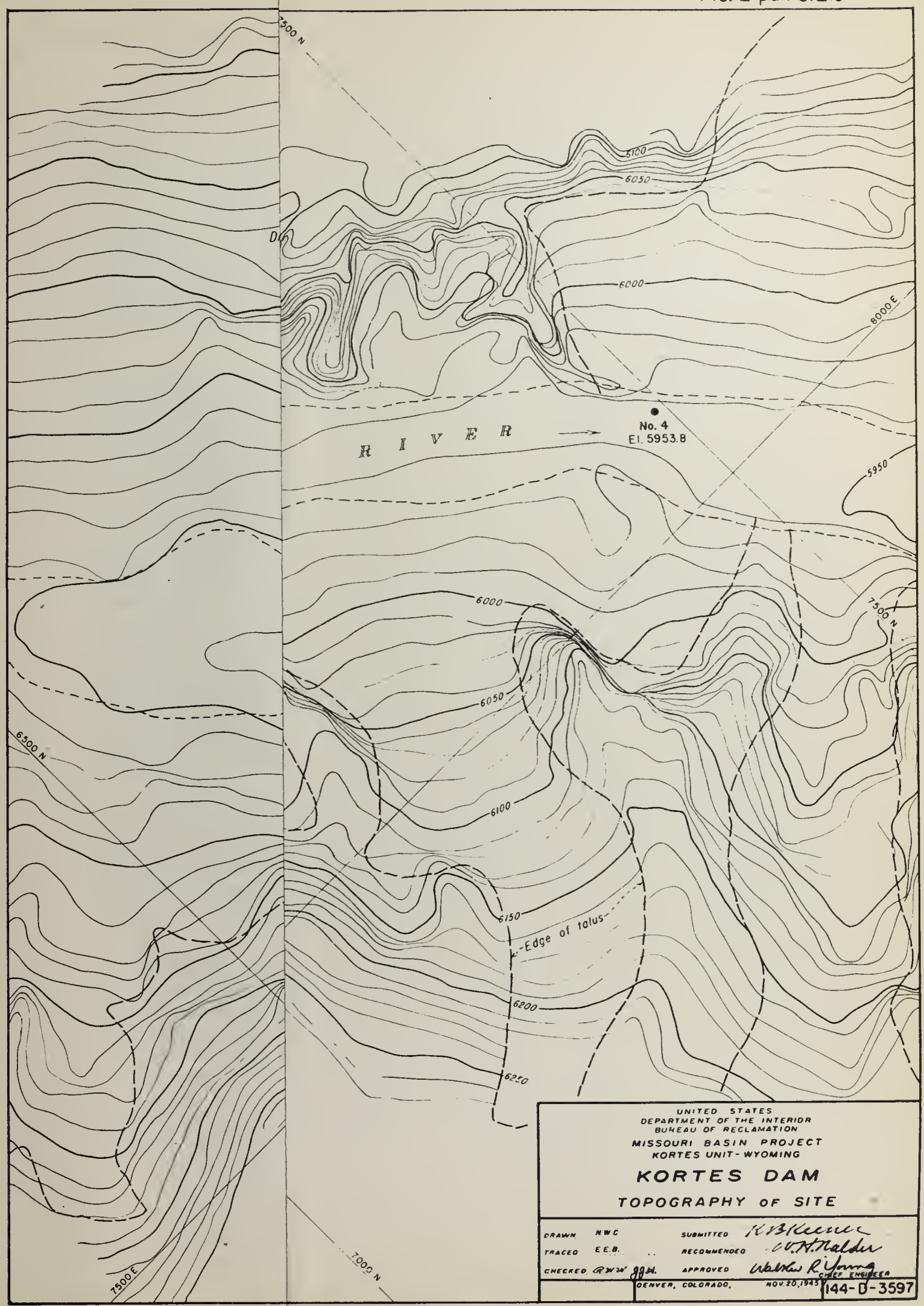
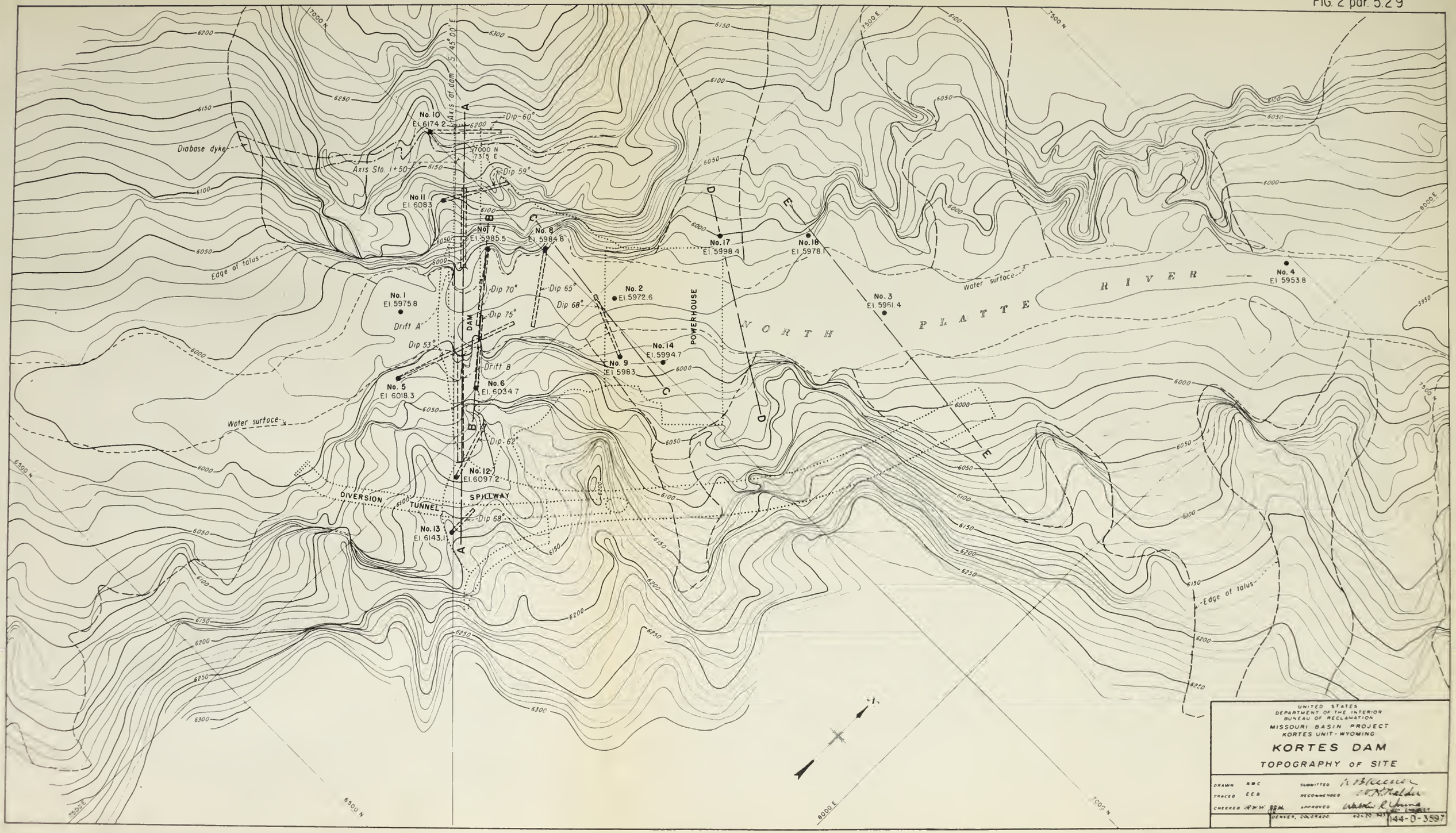

7500 N
5100
6050
6000
8000 E
No. 4
El. 5953.8
R I V E R
5950
6000
7500 N
6050
6500 N
6100
6150
Edge of talus
6200
6250
7500 E
7000 N
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI BASIN PROJECT
KORTES UNIT - WYOMING
KORTES DAM
TOPOGRAPHY OF SITE
DRAWN N.W.C.
TRACED E.E.B.
CHECKED R.W.W. J.H.
SUBMITTED K.B.Keener
RECOMMENDED C.H.Malder
APPROVED Walker R. Young
CHIEF ENGINEER
DENVER, COLORADO, NOV. 20, 1945
144-D-3597

FIG. 2 par. 5.2 9



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI BASIN PROJECT
KORTES UNIT - WYOMING
KORTES DAM
TOPOGRAPHY OF SITE
DRAWN RWC
TRACED EEB
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO
144-D-3597
NORTH PLATTE RIVER
POWERHOUSE
DAM
DIVERSION TUNNEL
SPILLWAY
Diabase dyke
Axis Sta. 1+50
Axis of dam S 45° 00' E
Edge of talus
Water surface
Drift A
Drift B
No. 1 El. 5975.8
No. 2 El. 5972.6
No. 3 El. 5961.4
No. 4 El. 5953.8
No. 5 El. 6018.3
No. 6 El. 6034.7
No. 7 El. 5985.5
No. 8 El. 5984.8
No. 9 El. 5983
No. 10 El. 6174.2
No. 11 El. 6083
No. 12 El. 6097.2
No. 13 El. 6143.1
No. 14 El. 5994.7
No. 17 El. 5998.4
No. 18 El. 5978.1
Dip 60°
Dip 59°
Dip 70°
Dip 75°
Dip 53°
Dip 65°
Dip 68°
Dip 62°
Dip 68°
7000 N
7315 E
7500 N
7500 E
8000 E
6500 N

(.9) and the tie-in point with the horizontal control system indicated. The coordinate system used will usually parallel the true points of the compass and the origin of coordinates will be so located that all construction will fall in one quadrant. In like manner, the zero station of the axis is selected so that no negative stations will occur in the area of construction. An example of construction site topography illustrating details to be shown is given in Figure 2.

LOG OF TEST HOLES

.10 The complete history of foundation explorations will be indicated in a log of test holes, test pits, and exploration tunnels made in the field as provided in Chapter 2.3 of the Project Planning Handbook. Data based upon the results of these explorations, which will be prepared and submitted by the Geology Section of the Engineering and Geological Control and Research Division, will indicate the geological structure and composition of the foundation rock. Preliminary excavation and foundation treatment studies will be based upon the information gained from this log. A specification drawing will be prepared showing in plan the topography, location and direction of each hole, and an outline of the proposed structure in order to show its relation to the foundation exploration. Several profiles along the lines of test holes will then be drawn and a cross-section of each hole will be plotted in its relative position and the characteristics and types of the various foundation strata indicated.

GENERAL DRAWING

.11 In order to show a general picture of the dam and appurtenant structures, and the relative location and relationship of the principal elements, a general drawing is prepared consisting of a plan, elevation, and typical transverse sections. Figure 3 illustrates the amount of detail shown on such a drawing.

PLAN

A. The plan will show the horizontal projection of the completed structure, topography, orientation of the structure with respect to the coordinate system, stationing of principal features, location of contraction joints, and intersection of excavation slopes with original ground surface.

ELEVATION

B. The elevation will indicate the vertical projection of the upstream face. The profile shown is that of the assumed line of excavation along the axis of the dam. Depending upon the importance or size of the structure, a downstream elevation may also be included. The principal details noted include elevations and stationing of critical points and features, numbering

(.11B)

and usually the width of construction blocks, dimensions of the spillway and size of gates, and the trace of the original ground surface.

SECTIONS

C. Sufficient transverse sections are shown to give a general picture of each major feature. On these sections will be indicated critical elevations of headwater and tailwater, slopes of the faces of the dam, and general dimensions of galleries and other openings through the structure.

AREA, CAPACITY, DISCHARGE CURVES

D. If room permits, a chart of reservoir area, capacity, and discharge curves will also be included on this drawing. If the detail to be shown requires a scale which will not permit the inclusion of these curves on the general drawing, a separate chart of area, capacity, and discharge curves will be prepared for the specifications. These curves are important since they indicate, for various elevations of the reservoir, the capacity of the various outlet features and reservoir storage capacity and may influence the decision on the method of river diversion during construction.

MAXIMUM SECTIONS

.12 In order to show greater detail of the size, shape, and principal features of the structure, a drawing is prepared containing the maximum sections through the spillway and nonoverflow portions of the dam. On this drawing will be indicated all possible details necessary for a clear and accurate study of the sections. Those details which cannot be made clear will require further enlargement, such as the section through the top of the dam showing dimensions of roadway, walks, and parapet walls, or sections indicating such details as drainpipe caps. Figure 4 illustrates the amount of detail usually included and manner of presenting the details in this drawing.

DIVERSION AND CARE OF RIVER

.13 The problem of caring for the river during construction of the dam involves many local factors, only a few of which are common to every site.

REQUIREMENTS

A. The principal requirements of any diversion plan are to provide adequate facilities for handling the normal river flow and to provide additional capacity for passing any anticipated floods without damage to the structure. The first requirement is satisfied by the means of diversion chosen. The second requirement will be satisfied by making the diversion capacity

FIG. 3 par. 5.2.11

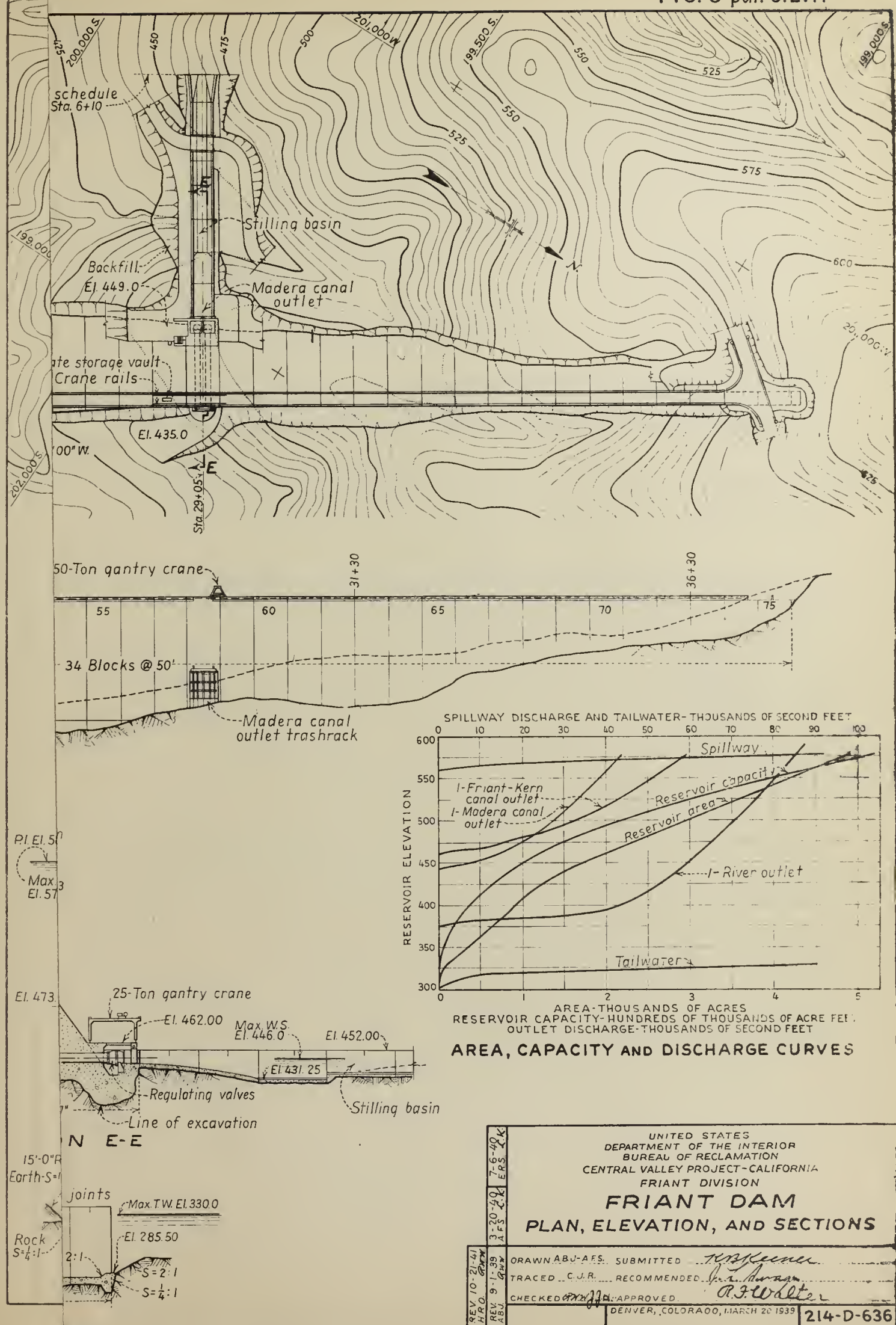


FIG. 3 par. 5.2.11

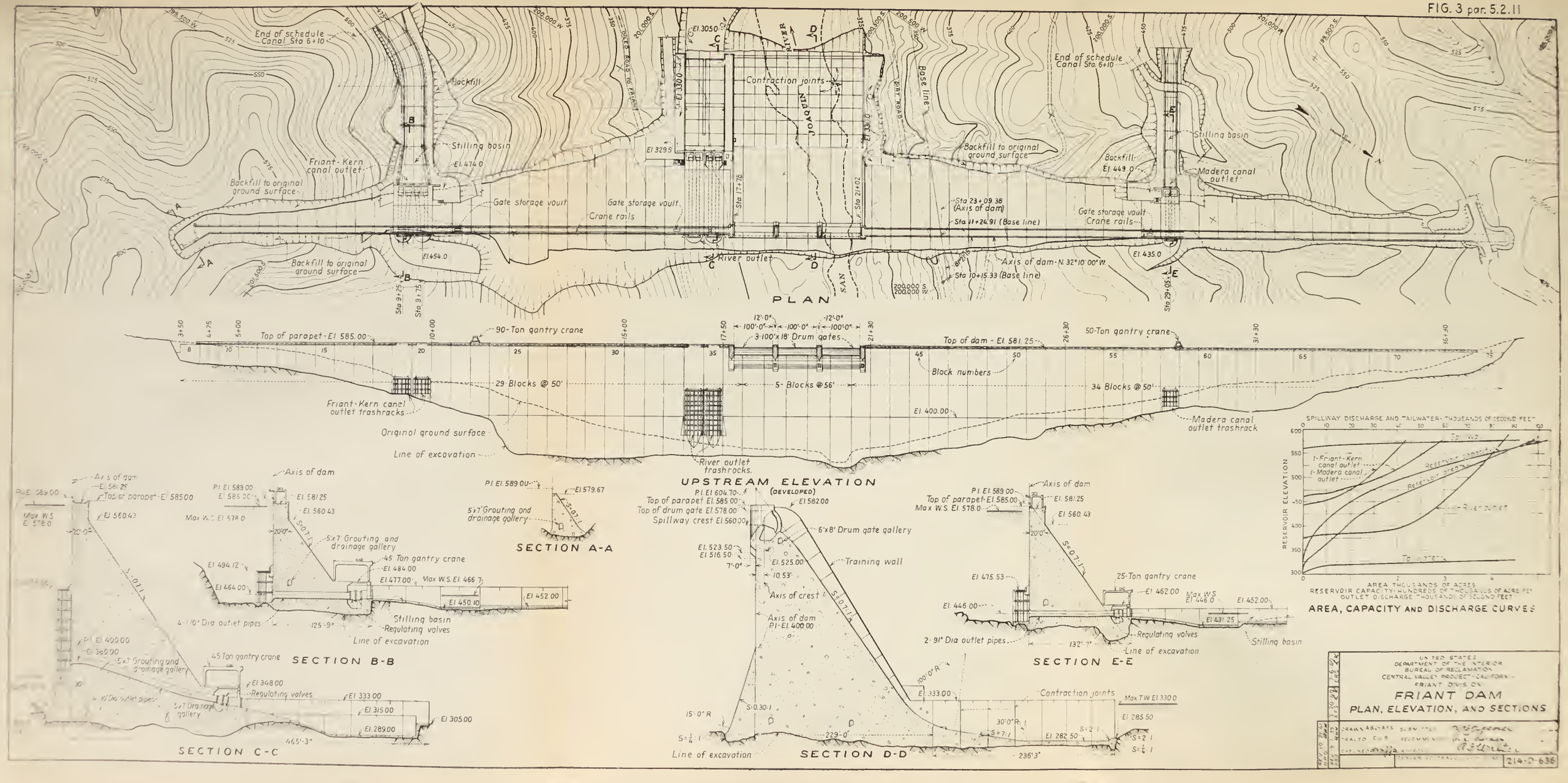


FIG. 4 par. 5.2.12

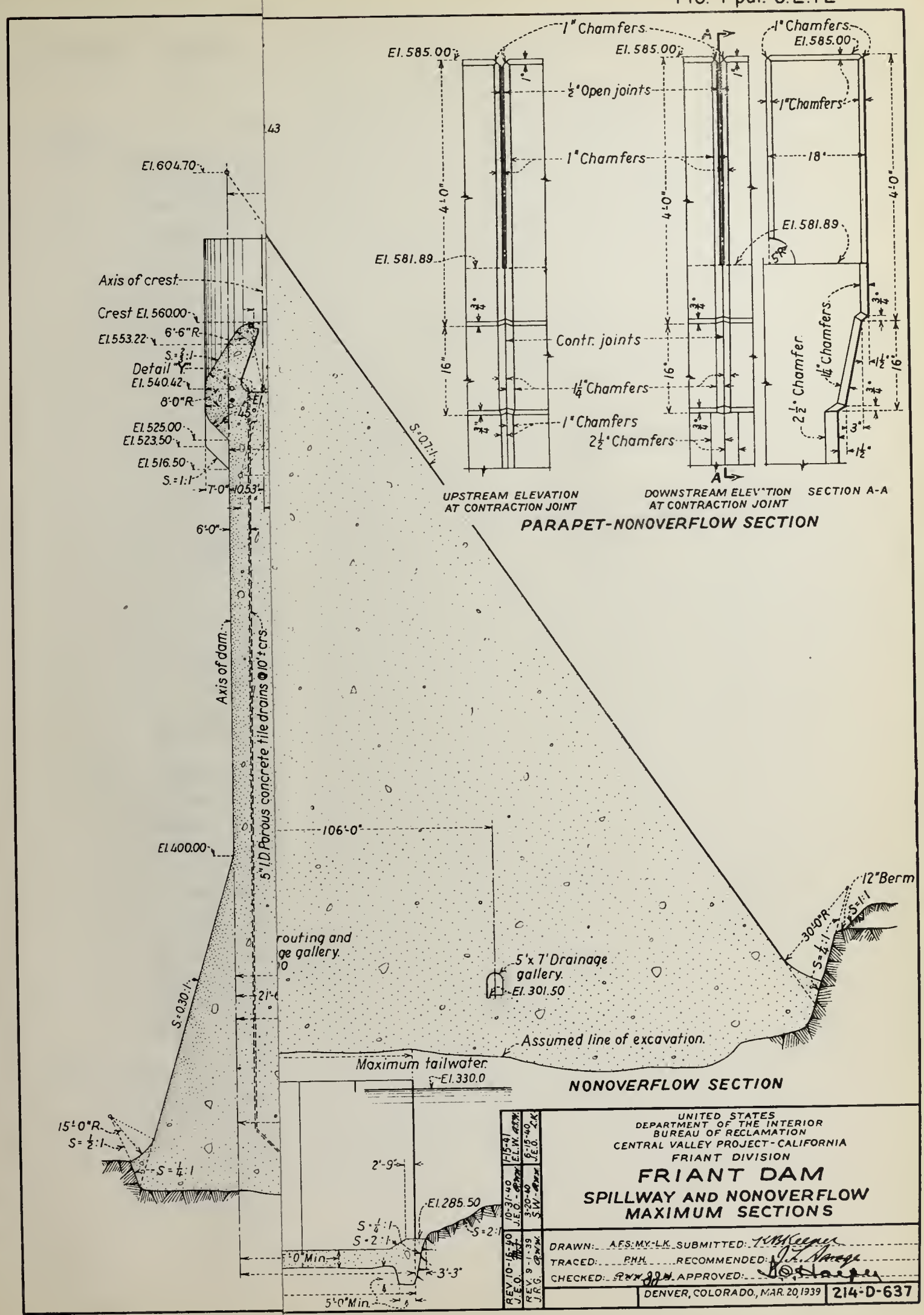
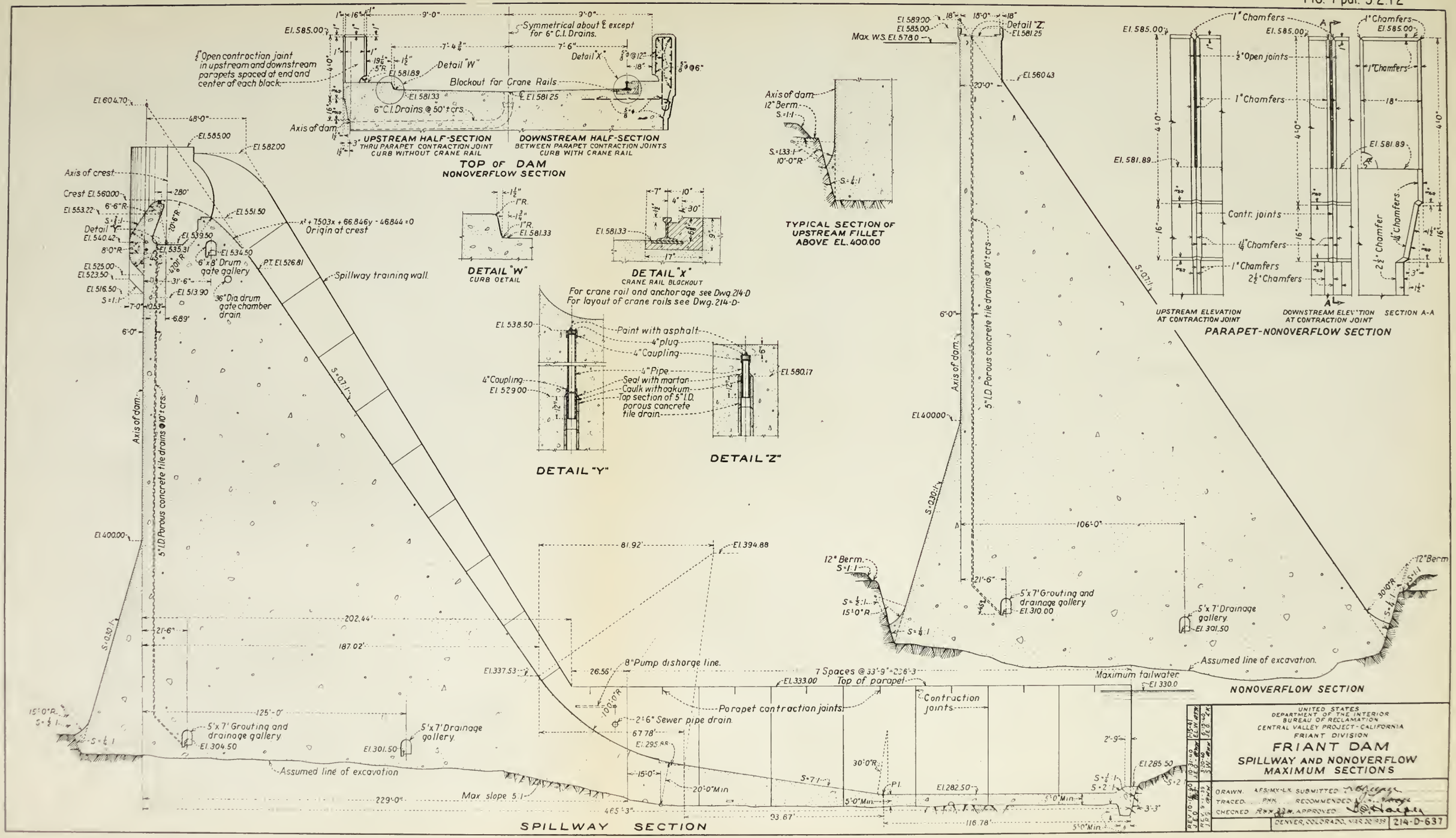


FIG. 4 par. 5.2.12



(.13A)

sufficient to take care of floods, or by a proper coordination with the construction schedule so that additional facilities of the structure itself will be completed in time to accommodate the expected high water.

CONSIDERATIONS

B. The most economical method of satisfying the above requirements can be determined only after a detailed study of the following general items:

(1) Normal flow of the river for all periods of the year,

(2) Estimates of frequency and size of probable floods during the construction period,

(3) Structural features of the dam itself and the physical features of the construction site which may suggest possible methods of diversion,

(4) Probable construction schedule of the dam,

(5) Demand for water below the damsite during the construction period, and

(6) Cost of various schemes.

RISK

C. Usually the Government does not prescribe the capacity of the diversion works, nor the details of diversion method to be used. Since various contractors will usually present different schemes, the schedule of bids will require diversion of the river to be included as a lump-sum bid. The capacity of diversion facilities greatly affects the cost and, except for very few cases, it is uneconomical to provide for maximum floods. Usually the facilities are designed to take care of expected seasonal or flash floods. An element of risk is therefore involved which is assumed by the contractor and is reflected in his bid.

DIVERSION METHODS

.14 Common practice in diverting streams during construction periods may utilize one or a combination of the following provisions: tunnels driven through the abutments, openings through the dam itself, and diversion of the flow over the tops of alternate construction blocks. The method adopted will largely depend upon the features of the spillway and power or irrigation outlet works of the dam.

(.14)

DIVERSION THROUGH TUNNELS

A. In tunnel diversion, the streamflow is bypassed around the construction area through tunnels in one or both abutments. Many dams require tunnels to carry the spillway overflow or to carry penstocks to the powerplant. These tunnels may be utilized in the diversion scheme by laying out and boring the diversion tunnel so that it will join the lower portion of the permanent tunnel as indicated in Figure 5. In this way, only a portion of the total cost of tunneling required for diversion purposes is chargeable to the cost of diversion.

GATES

(1) Some means of controlling the flow will be placed in the upstream portion of the tunnel. This may consist of a wood or steel bulkhead or slide gate which will permit total closure of the tunnel during plugging operations, and a partial closure, allowing only sufficient water to pass to satisfy downstream needs, after storage of water in the reservoir has been started.

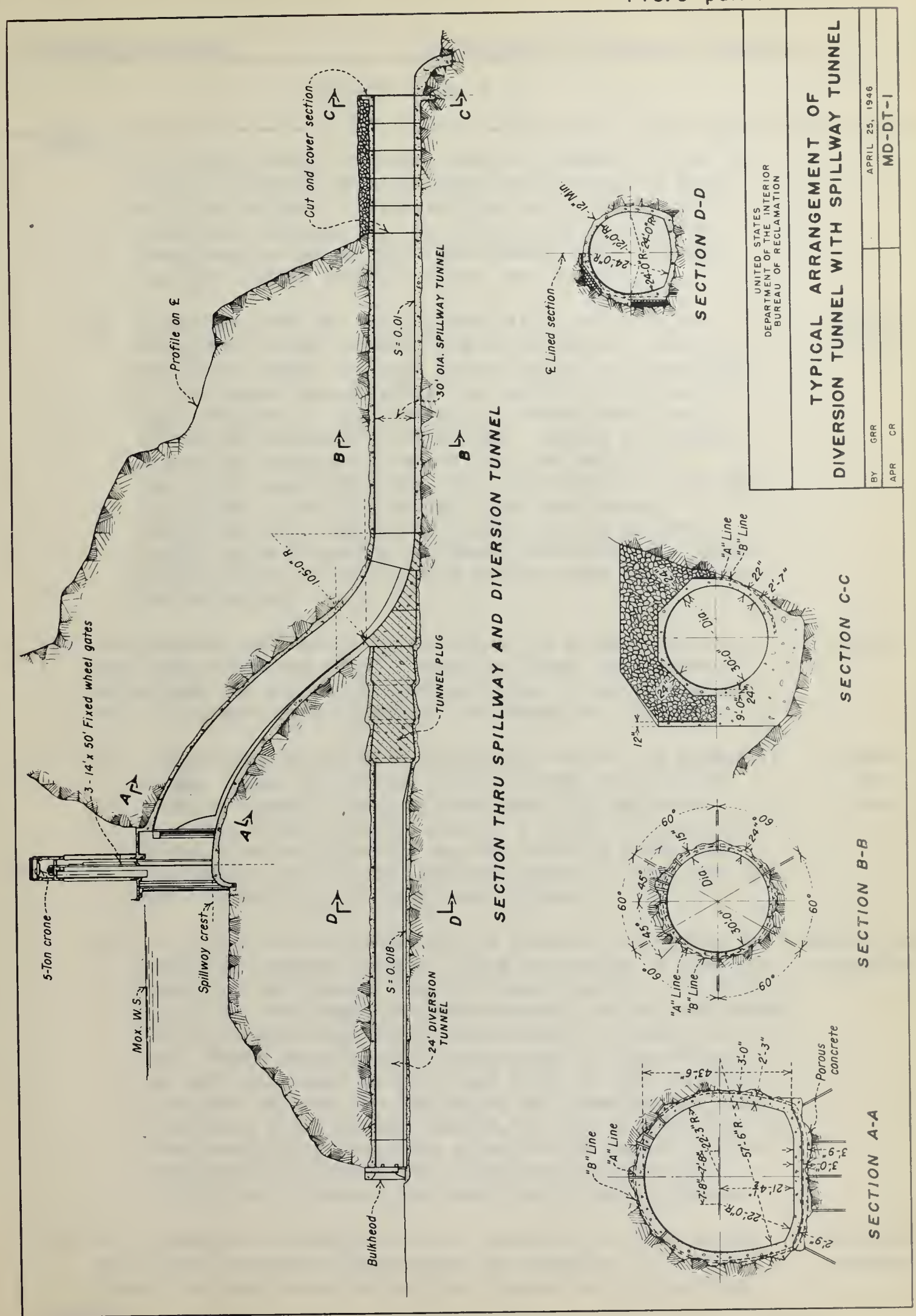
TUNNEL PLUG

(2) Permanent closure of the diversion tunnel is made by placing a massive concrete plug in the tunnel. Where the tunnel passes close to and under the dam, the plug may be located near the upstream face to serve as a cutoff or may extend entirely under the dam depending upon the condition of the rock. Where the diversion tunnel joins a permanent tunnel, the plug is located immediately upstream from the intersection as indicated in Figure 5. The plug is designed to be keyed into the tunnel by wedge-shaped keys. Prior to diversion, the portion of the tunnel which will contain the plug is lined with concrete, the surface of the lining conforming to the wedge-shaped keys. After the plug has been cast and cooled, grout is forced through previously installed grout connections into the joint between the concrete tunnel lining and the plug to insure a watertight joint. Depending upon the size of the plug, more effective control of temperature and contraction will be obtained by embedding pipes in the plug sections for artificial cooling.

DIVERSION THROUGH OPENINGS

B. Another method of diversion is through openings in the dam itself. These openings may be placed in the lower regions solely for the purpose of diversion, or they may be openings which later will form part of

FIG. 5 par. 5.2.14



(.14B)

the outlet works or power penstock systems. As in the case of tunnels, some provision for control of flow will be included. After serving their purpose, all diversion conduits will be filled with concrete for their entire length, provision having been made for key-ways, water seals, cooling, and grouting.

C. Diversion over the tops of partially completed construction blocks is usually done in stages. During the first stage, the flow is restricted to one portion of the river channel while the portion of the dam in the remainder of the channel is constructed to an elevation favorable to diversion. During the second stage, the river is diverted over the top of a partially completed block while the portion of the dam is placed in the first-stage diversion channel. Following this, the dam is carried to its ultimate height while diversion continues over alternate blocks until use can be made of the outlet works designed for the structure. DIVERSION OVER DAM

.15 A cofferdam, as used in construction, is actually a temporary dam or barrier which is used to divert the stream or to enclose and isolate certain portions of the stream bed while excavation and foundation construction proceed. COFFERDAM

A. Conventional types of cofferdam are earth- and rock-fill dikes, timber or precast concrete cribs filled with earth or gravel, steel or wood sheet piling, sheet pile cells, and concrete walls. A study of local conditions, plan or layout of the dam, and the materials available close to the site will generally indicate the most suitable type of cofferdam to use. PURPOSE AND TYPES

B. The principal considerations in planning cofferdams are sufficient height, safety during the period of use, and provision for removal when no longer needed. The height should be such that the cofferdam will not be overtopped by anticipated high river flows during the period of its use. Where prevention of overtopping is impracticable, the work area must be permitted to be flooded and provision must be made for unwatering and cleaning the area after each flood stage. Safety, in addition to security from overtopping, requires attention to the effect that excavation and unwatering of the foundation in the vicinity will have on the stability of the cofferdam. CONSIDERATIONS IN PLANNING

.16 All operations connected with the treatment of the foundation have as their ultimate goal the formation of a sound, impervious, and consolidated base capable of withstanding FOUNDATION TREATMENT

(.16)

FOUNDATION TREATMENT (CONT.)

all the stresses induced by the superimposed loaded structure. These operations can be divided into two parts:

A. The excavation operations consisting of the removal of all objectionable material above the sound rock foundation, and

B. The subsequent subsurface operations consisting of grouting and drainage treatments. The thoroughness with which the foundation explorations have been carried out materially affects the knowledge of foundation conditions and facilitates the determination of preliminary estimates of depths and slopes for common and rock excavation, and depths and extent of subsequent drilling and grouting operations.

EXCAVATION

.17 Excavation operations must be conducted in such a manner as to preclude any damage to the underlying sound rock. The removal of the relatively loose overburden usually can be accomplished without any resulting damage. Excavation slopes are made as steep as possible consistent with stable banks. The excavation of the rock will be done at all times in such a manner that no shattering or opening of seams will develop on the contact surface between the dam and foundation. Blasting operations, therefore, will be strictly controlled. When continued use of explosives is likely to crack the surface or open seams, its further use will be prohibited and the remainder of the rock will be removed by such methods as wedging, barring, channeling, or line drilling. The final depth of excavation can only be determined after actual inspection of the exposed surface, and excavation must be carried on until a foundation surface on sound rock is exposed which is free from any weathered material, open seams, or other objectionable defects.

SURFACE SHAPING

During the course of excavation a plan of final shaping is followed which will produce a rock surface roughly stepped in appearance that will increase the sliding resistance and bond with the concrete. Additional shaping is done to moderate steep downward slopes in a downstream direction and to prevent any sharp reentrant angles being formed in the contact surface of the structure with the foundation. Immediately before concrete is placed, it is necessary to make a final clean-up, removing all loose fragments, spalls, dirt, grout, oil, grease, or other objectionable material. To insure complete bonding and water-tightness, a thin layer of mortar is placed over the surface and worked into all irregularities with wire brushes.

FOUNDATION GROUTING

.18 The principal objective of foundation grouting is to establish an effective barrier to seepage, thereby reducing hydrostatic uplift under the structure. A secondary objective is to consolidate the rock under the structure, and thus secure a more unified and monolithic foundation. The procedure that is followed in grouting the foundation is governed by the height of the structure and the characteristics of the foundation rock. No definite rules can be laid down for the grouting program.

Since the structural characteristics of the foundation will differ for each project, any plan for a grouting program can only be tentative and will be modified in the field to suit actual conditions after actual grouting operations are started.

Grouting operations are usually accomplished from the surface of the ground or from galleries within the structure. However, it is often advantageous and sometimes necessary to grout the foundation from some point beneath the ground surface in order to insure a thorough job of consolidation. For this purpose, shafts may be sunk into the rock and tunnels driven generally parallel to the axis of the dam. Tunnels may also be driven into the abutments at higher elevations. Access to the tunnels after the placing of structural concrete has been started is usually through the foundation gallery. The depth and extent of these tunnels will depend upon the location and extent of the fracture zones. These tunnels also provide means of access to the foundation for any future treatment should unsatisfactory subsurface conditions develop after the structure is completed and the reservoir filled.

The general plan for grouting the foundation rock under the dam provides for preliminary low-pressure shallow grouting to be followed by final high-pressure deep grouting. The shallow holes for the low-pressure grouting are designated as "B" holes, the deep holes for the high-pressure grouting as "A" holes, and holes for supplemental grouting that may be required for a particular purpose are called "C" holes, and so on. "High pressure" and "low pressure" are relative terms only; the pressures that are used are usually the maximum to insure the complete filling of all cracks and voids without causing any uplift or lateral displacement of foundation rock. Depending upon foundation conditions, the pressures used in high-pressure grouting on one project may be less than those used in low-pressure grouting on another project.

(.18)

LOW-PRESSURE GROUTING

A. Low-pressure grouting is applied to the surface zones to provide a general consolidation of the surface rock and to fill and seal major surface seams and crevices. Usually this operation is carried out before any of the concrete of the structure is placed. This is accomplished by drilling and grouting relatively shallow holes, called "B" holes. The extent of area grouted and depth to which these holes are drilled will depend upon local conditions.

Preliminary programs usually call for three or more lines of holes parallel to the axis of the dam with lines about 20 feet apart and holes approximately 20 feet apart on line and from 20 to 50 feet deep. In the execution of the program, holes are drilled and grouted from 40 to 80 feet apart before the intermediate holes are drilled. The amount of grout which these holes accept determines whether further intermediate holes should be drilled. This process is continued until it is reasonably assured that all seams, cracks, and voids have been filled.

LOCATION OF HOLES

(1) "B" hole grouting is usually applied in the general area of the heel of the dam, although local conditions may dictate that it be applied over the entire foundation. The upstream line of holes should lie upstream from the heel to furnish a cutoff for leakage of grout from the high pressure holes used later in the same area. The holes are usually drilled normal to the surface unless it is desired to intersect some known seam at an angle. The pressures used are usually as high as allowable without disturbing the rock, in order to obtain as much penetration of grout as possible into the seams.

CLEANING OF HOLES

(2) Prior to grouting and after hole connections have been anchored in the rock, the holes should be cleaned by washing with alternate jets of air and water, introduced at the bottom of each hole through a blowpipe, in order to remove any drill cuttings and dirt from seams.

HIGH-PRESSURE GROUTING

B. High-pressure grouting is applied to holes, called "A" holes, drilled relatively deep near the upstream face to form the principal grout curtain or seepage barrier. Tentative designs will usually specify a single row to be drilled 5 feet on centers. In order to permit the application of high pressure without movement of

(.18B)

HIGH-PRESSURE GROUTING (CONT.)

foundation surface layers or loss of grout through surface cracks, this grouting procedure is carried out subsequent to low-pressure grouting operations and after some of the structural concrete has been placed. Usually the procedure will be accomplished from galleries within the structure. However, when no galleries are provided, as is the case for some low gravity and arch dams, the high-pressure grouting must be done from the heel of the dam before storage of water commences in the reservoir.

The drilling of holes should be so conducted that the base of the grout curtain will be located on the vertical projection of the heel of the dam. If drilled from a gallery that is some distance from the upstream face, the holes may be inclined as much as 15 degrees upstream from the plane of the axis. If the gallery is near the upstream face, the holes will be nearly vertical. When the holes are drilled from the upstream face, they are usually inclined downstream. Characteristics of the foundation seams may also influence the amount of inclination.

PROCEDURES

(1) To facilitate drilling procedures after concrete has been placed, pipes usually 2-1/2-inches in diameter are grouted into the rock foundation 2 to 5 feet before the structural concrete is placed. These pipes extend high enough to reach the grouting gallery or upstream face and are capped to prevent their being plugged when the concrete is placed. When the structure has reached a prescribed elevation, the grout holes are then drilled and grouted through these pipes. Although the tentative grouting plan may indicate holes to be drilled 5 feet center to center, the actual procedure will be to drill and grout holes approximately 40 feet apart, or as far apart as necessary to prevent grout from one hole escaping to another drilled but ungrouted hole. A second set of holes, located midway between the first set, will then be drilled and grouted. This procedure continues until the 5-foot spacing is reached or until the amount of grout accepted by the last group of intermediate holes indicates no further drilling to be necessary.

DEPTH

(2) The depth to which the holes are drilled varies greatly with the characteristics of the foundation and the hydrostatic head. In a hard, dense foundation, the depth may vary from 20 to 30 percent of the head. In poorer foundation the holes are

(.18B-2)

deeper and may reach as much as 70 percent of the head. During the progress of the grouting, local conditions will dictate the depth. In fact, the depth of the required grout curtain may not be determined until after the total water load has come on the dam and observations have been made of the rate of seepage and the accompanying uplift.

SUPPLEMENTARY "C" HOLE GROUTING

(3) In the case of high dams where the foundation gallery is located at a relatively long distance from the upstream face, such as in Grand Coulee and Shasta Dams, "A" hole grouting may be supplemented by a line of holes, called "C" holes, drilled from the upstream face of the dam and inclined downstream in order to intersect the main grout curtain. The depth of these holes is approximately 75 feet and their spacing is usually the same as for the "A" holes. The supplementary grout curtain formed by grouting this line of holes serves to reduce the hydrostatic uplift that would otherwise be exerted on the portion of the base between the upstream heel and the gallery. Drilling and grouting procedures are accomplished immediately prior to the drilling and grouting of the "A" holes.

METHODS OF GROUTING

C. Usually the foundation will increase in density and tightness of seams as greater depths are reached, and the pressure necessary to force grout into the tight joints of the deep planes may be sufficient to cause displacements of the upper zones. Two general methods of grouting are used, each permitting the use of higher pressures in the lower zones.

STAGE GROUTING

(1) The stage grouting or successive grouting method consists of drilling a hole to a limited depth or to the intersection with an open seam, grouting to that depth, cleaning out the hole after the grout has taken its initial set, then drilling and grouting the next stage. This process is repeated, using higher pressures for each succeeding stage, until the final depth is reached.

PACKER GROUTING

(2) Packer grouting consists of drilling the hole to its final depth and grouting the lowest high-pressure zone by extending the grout pipe to the top of this zone. A flexible seal or packer between the end of the grout pipe and the wall of the hole prevents the grout from rising. The

grout pipe is then raised so that the seal is at the top of the next zone to be grouted using somewhat lower pressure. This process is repeated until all the zones have been grouted.

(3) Each method possesses relative advantages and disadvantages. The method used will probably be dictated by the nature of the foundation. Where the rock is fairly tight, packer grouting may be faster and more effective. On the other hand, if the foundation is relatively seamy, there is danger of grout leaking past the packer and the packer becoming grouted into the hole. The stage grouting method may also use packers if it is desirable to prevent the higher pressures from being exerted on zones previously grouted. RELATIVE MERITS

.19 Very often the exploratory drilling or the final excavation uncovers faults, seams, or shattered zones which extend to such depths before they pinch out that it is impracticable to attempt to clean them out entirely. These conditions require special treatment in one form or another and the procedure for reinforcing, and consolidating such weak zones is frequently called "dental treatment." In general, these seams are excavated and backfilled with concrete to a depth sufficient to produce elastic qualities and bearing strength equal to the surrounding sound foundation rock. TREATMENT OF FAULTS AND SEAMS

Theoretical studies have been made to develop general rules for guidance as to how deep transverse seams should be excavated. These studies, based upon foundation conditions and stresses at Shasta and Friant Dams, resulted in the following approximate formulae: THEORETICAL RULES

$$d = 0.002bH + 5 \quad \text{for} \quad H < 150 \text{ ft.}$$
$$d = 0.3b + 5 \quad \text{for} \quad H \geq 150 \text{ ft.}$$

in which: H = height of dam above general foundation level in feet
b = width of weak zone in feet
d = depth of excavation of weak zone below surface of adjoining sound rock

d for clay gouge seams shall not be less than 0.1H

These rules give a means of approach to the question of how much should be excavated but final judgment must be exercised in the field during actual operations. The

(.19)

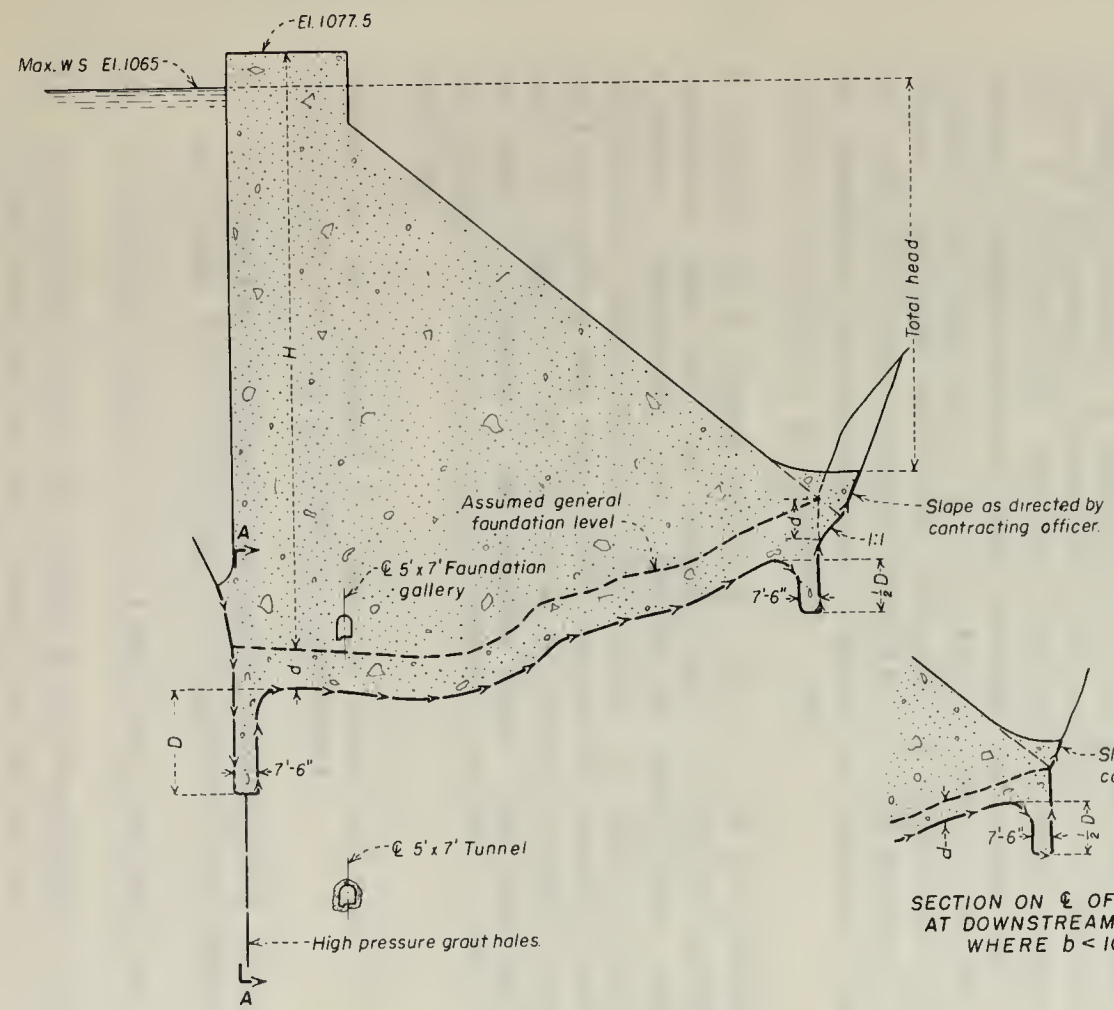
THEORETICAL RULES (CONT.)

depth of the trench formed by use of the above rules will satisfy stress conditions of a normal foundation, but does not provide a long enough percolation path to prevent seepage. For this reason, upstream and downstream cutoff shafts are excavated on each seam and backfilled with concrete to a depth such that the ratio of total path of percolation to the total head, called the percolation factor, will be not less than 4.0 for clay gouge seams nor less than 2.5 for all other seams. The path of percolation is considered to be the distance along the line of contact of concrete with foundation material from upstream to downstream faces. The total head is the difference in elevation from maximum water surface in the reservoir to the point of contact of concrete and undisturbed foundation at the downstream face. The width of the shaft is equal to b plus 2 feet but shall not be less than 5 feet. The thickness of the shaft parallel to the direction of flow shall be 7 feet 6 inches. The depth of the upstream shaft shall be twice the depth of the downstream shaft. Figure 6 shows a typical section through a dam and illustrates the various factors discussed above.

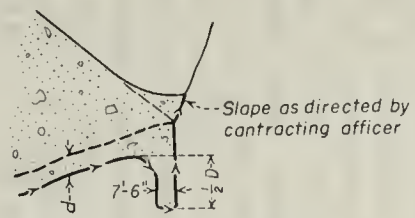
Other adverse foundation conditions may be due to horizontally bedded clay and shale seams, caverns, or springs. Procedures for treating these conditions will vary and will depend upon field studies of the characteristics of the particular condition to be remedied.

FOUNDATION DRAINAGE

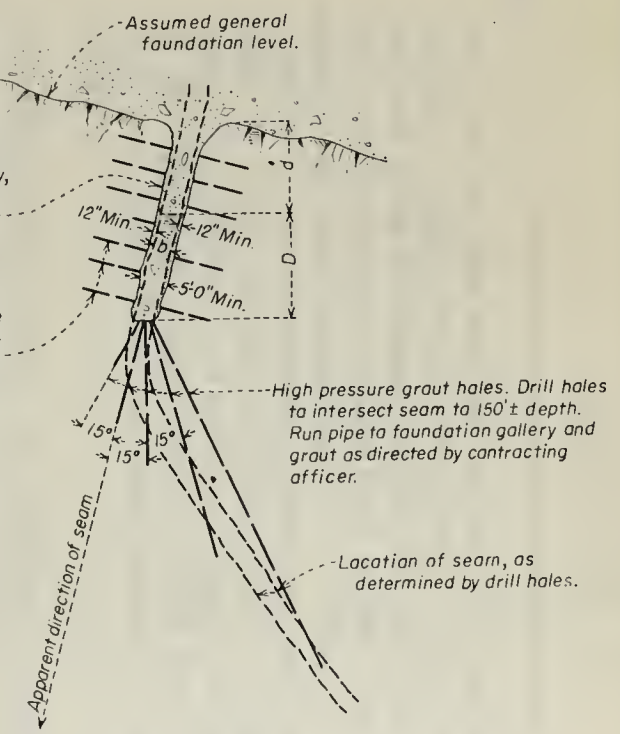
.20 The final treatment of the foundation is to provide drainage. Although a well executed grouting program will materially reduce seepage, some means must be provided to intercept the water which will percolate through and around the grout curtain and, if not removed, may build up prohibitive hydrostatic pressures on the base of the structure. Drainage is accomplished by drilling one or more lines of holes immediately downstream from the main grout curtain. The size, spacing, and depth of these holes are arbitrarily assumed based upon good engineering judgment of the physical characteristics of the rock and the effectiveness of the grouting operations. The chief factor influencing size is the possibility of their becoming clogged with mineral leachings. The diameter should not be less than that produced by an AX core drill, which is 1-7/8 inches. Recent practice has been to use an NX drill, which produces a hole 3 inches in diameter. The spacing and depth is influenced by the foundation conditions and the depth of the reservoir. Usually plans call for an ultimate spacing of 5 feet center to center and a depth varying from 20 to 40 percent of the hydrostatic head.



TYPICAL SECTION ON ℄ OF SEAM



SECTION ON ℄ OF SEAM AT DOWNSTREAM TOE WHERE b < 10'



SECTION A-A

GUIDE FOR GENERAL EXCAVATION OF WEAK ZONES

b = Width of zone
d = Depth of excavation in the zone below the surface of adjoining sound rock.
H = Height of dam above the general foundation level.
$H \geq 150'$ $d = 0.02bH + 5'$ } or as modified by
$H < 150'$ $d = 0.3b + 5'$ } contracting officer.
Note: Depth of excavation (d) in clay gauge seams shall be not less than 0.10H.

GUIDE FOR EXCAVATION OF CUT-OFF SHAFTS

D = Depth of upstream cut-off shaft below the level of general excavation in weak zone. Minimum D = 40'.
——>——>—— = Path of percolation.

$$\text{Percolation factor} = \frac{\text{Path of percolation}}{\text{Total head}}$$

Percolation factor = 4.00 for clay gauge seams
= 2.50 for all other seams

Width of shaft = b + 12" Min. into sound rock on each side of seam. Minimum width of shaft = 5'-0".

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT - CALIFORNIA
KENNETT DIVISION

SHASTA DAM

TREATMENT OF WEAK ZONES IN FOUNDATION

DRAWN	H.E.M.	SUBMITTED	J. J. Hammond
TRACED	E.F.J. - F.B.	RECOMMENDED	J. B. Kennel
CHECKED	RWW	APPROVED	W. H. Nalder

DENVER, COLORADO - JAN 25, 1940 | 214-D-4140

TR. AND REV. 2-1-40 H.E.M. RWW
REV. 2-7-40 H.E.M. RWW

FIG. 6 par. 5.2.19

(.20)

Drain holes are drilled after all foundation grouting has been completed in the area. They are usually drilled from drainage galleries within the structure through previously installed metal pipe extending down almost to the foundation rock. When no gallery is provided, the drainage holes are drilled from the upstream face or from the top of some lift through previously installed pipes. After drilling, the pipes are plugged at the top and seepage water from the hole is taken off at a tee connection in the pipe which leads to a collection header. DRAIN HOLES

.21 Although final plans for foundation excavation, grouting, and drainage cannot be made prior to actual construction operations, preliminary foundation treatment designs are based upon geological studies of preliminary foundation explorations, in order to give the contractor some indication of the conditions which may exist and the extent of the drilling program. Based upon this tentative foundation treatment design, a drawing will be prepared showing a plan of foundation excavation, a profile of the foundation with a longitudinal section through the structure and several transverse sections through the structure to show location of galleries, and depth and spacing of drill holes. Enlarged sections through the galleries will be included in order to show details of pipe connections. Two examples of preliminary foundation treatment design drawings are given in Figures 7 and 8. SPECIFICATION DRAWING

.22 A gallery is a formed opening left in the structure after completion and may run transversely, longitudinally, or on a slope. Depending upon foundation conditions, construction conditions, and size and importance of the structure, a gallery system may vary from one short longitudinal gallery near the base of the dam to a relatively complicated system as shown in Figure 9 for Shasta Dam. The location, size, and shape of the galleries depend upon their use or purpose. GALLERIES

Galleries are located in dams to serve any one or a combination of the following purposes: PURPOSE

A. To provide drainage for water percolating through the upstream face or seeping through the foundation,

B. To provide space for drilling and grouting the foundation,

C. To provide space for headers and equipment used in artifical cooling of the blocks and grouting the contraction joints,

(.22)

D. To provide access to the interior of the dam for the inspection of its behavior after completion, and

E. To provide access to and room for mechanical equipment used in the operation of gates in the spillway and outlet works. The purpose of each gallery is usually indicated by its name.

FOUNDATION GALLERY

.23 The foundation gallery generally conforms, in elevation, to the outline of the canyon profile and, in plan, runs near and parallel to the axis of the dam. It is from this gallery that the holes for the main grout curtain are drilled and grouted and also from which the foundation drain holes are drilled. Its size, therefore, must be sufficient to accommodate a drill rig. There should be a minimum of 5 feet of concrete between the floor and the foundation rock, and not less than 20 feet between the upstream face and the gallery wall. Unless modified by local conditions, the usual distance from the upstream face to the gallery wall is approximately 10 percent of the head of water above the gallery.

DOWNSTREAM DRAINAGE GALLERY

.24 A supplementary drainage gallery is sometimes located further downstream, about two-thirds of the base width from the upstream face for the purpose of drilling and draining the downstream portion of the foundation. This gallery usually extends only through the deepest portion of the dam.

GATE GALLERY

.25 Gate galleries and chambers are placed in dams to provide access to and room for the mechanical equipment for the operation of gates in outlet conduits, power penstocks, or spillway crest. Their size will depend on the size of gates to be served.

GROUTING AND COOLING GALLERY

.26 When it is impracticable to grout the contraction joints from the face of the dam, the grout piping system will be arranged so as to locate the supply, return, and vent headers in galleries placed near the top of each 50-foot lift of concrete. The piping system for artificial cooling of the blocks will also be arranged to terminate in these galleries.

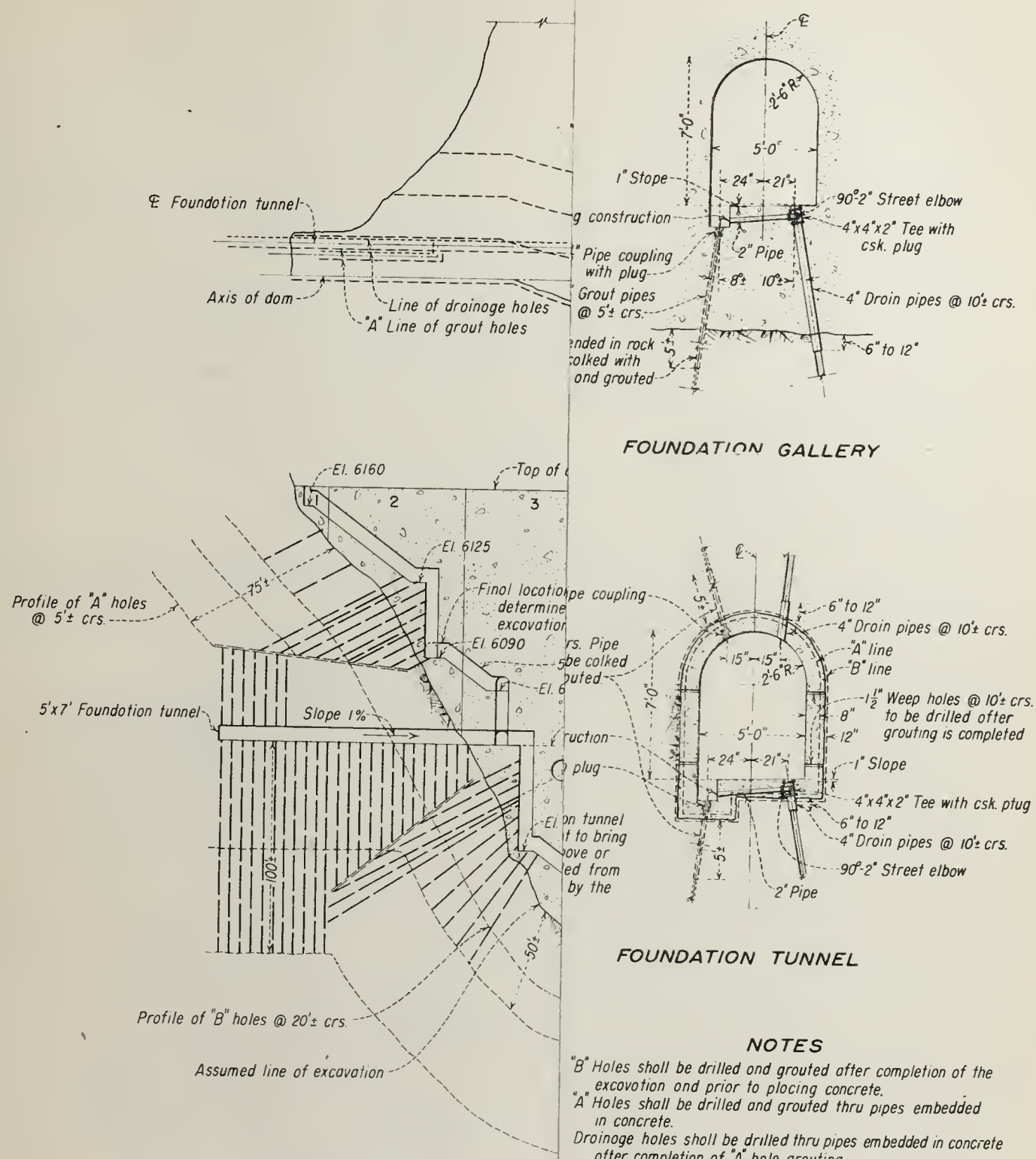
INSPECTION GALLERY

.27 Inspection galleries are located in a dam to provide access to the interior of the mass in order to inspect the structure and study the structural behavior of the dam after completion. All the galleries discussed above, which were located for specific purposes, also serve as inspection galleries.

ADITS

.28 The connecting passageways between the gallery system and features outside the dam, such as powerhouse or gatehouse, are called adits. Either solid or grilled doors are

FIG. 7 par. 5.2.21



FOUNDATION GALLERY

FOUNDATION TUNNEL

NOTES

"B" Holes shall be drilled and grouted after completion of the excavation and prior to placing concrete.

"A" Holes shall be drilled and grouted thru pipes embedded in concrete.

Drainage holes shall be drilled thru pipes embedded in concrete after completion of "A" hole grouting.

Final excavation line may differ widely from the assumed line of excavation shown.

PROF

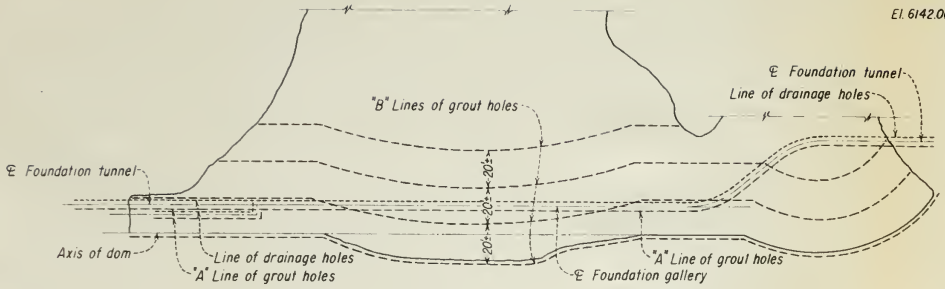
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI BASIN PROJECT
KORTES UNIT - WYOMING

KORTES DAM

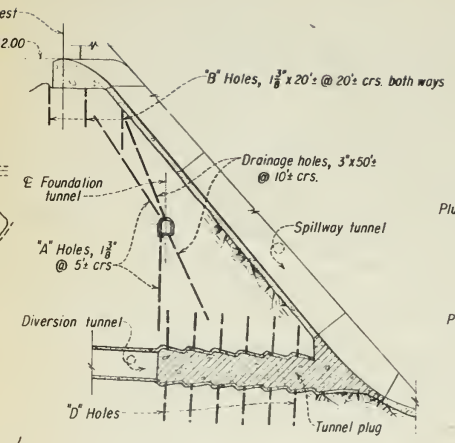
FOUNDATION GROUTING AND DRAINAGE

DRAWN	A.T.L.	SUBMITTED	K B Keener
TRACED	W.L.A.	RECOMMENDED	W. H. Nalder
CHECKED	RWW JJH	APPROVED	Walker R. Young, CHIEF ENGINEER
		DENVER, COLORADO	NOV. 20, 1945

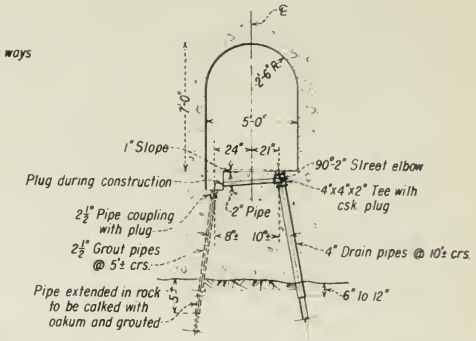
144-D-3601



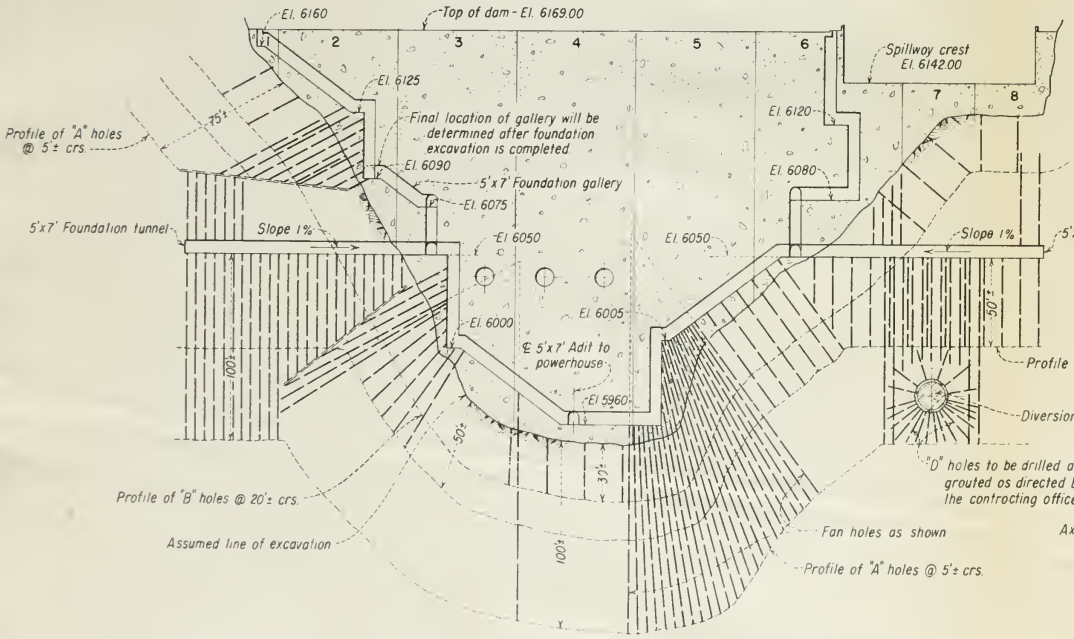
PLAN



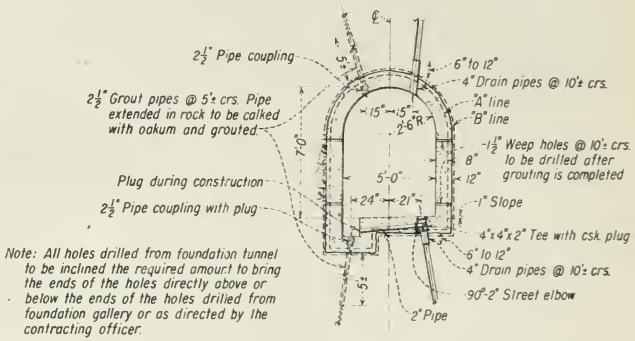
SECTION THRU ℄ SPILLWAY



FOUNDATION GALLERY

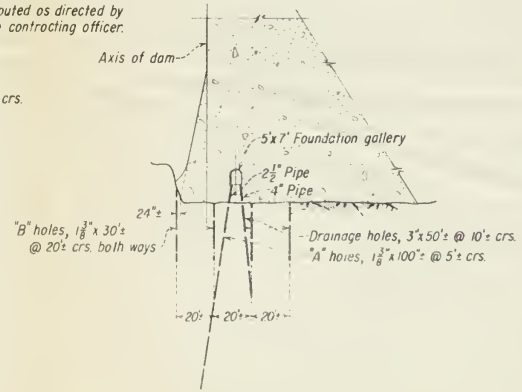


PROFILE OF FOUNDATION



Note: All holes drilled from foundation tunnel to be inclined the required amount to bring the ends of the holes directly above or below the ends of the holes drilled from foundation gallery or as directed by the contracting officer.

FOUNDATION TUNNEL



TYPICAL SECTION

NOTES

"B" Holes shall be drilled and grouted after completion of the excavation and prior to placing concrete.

"A" Holes shall be drilled and grouted thru pipes embedded in concrete.

Drainage holes shall be drilled thru pipes embedded in concrete after completion of "A" hole grouting.

Final excavation line may differ widely from the assumed line of excavation shown.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI BASIN PROJECT
KORTES UNIT - WYOMING

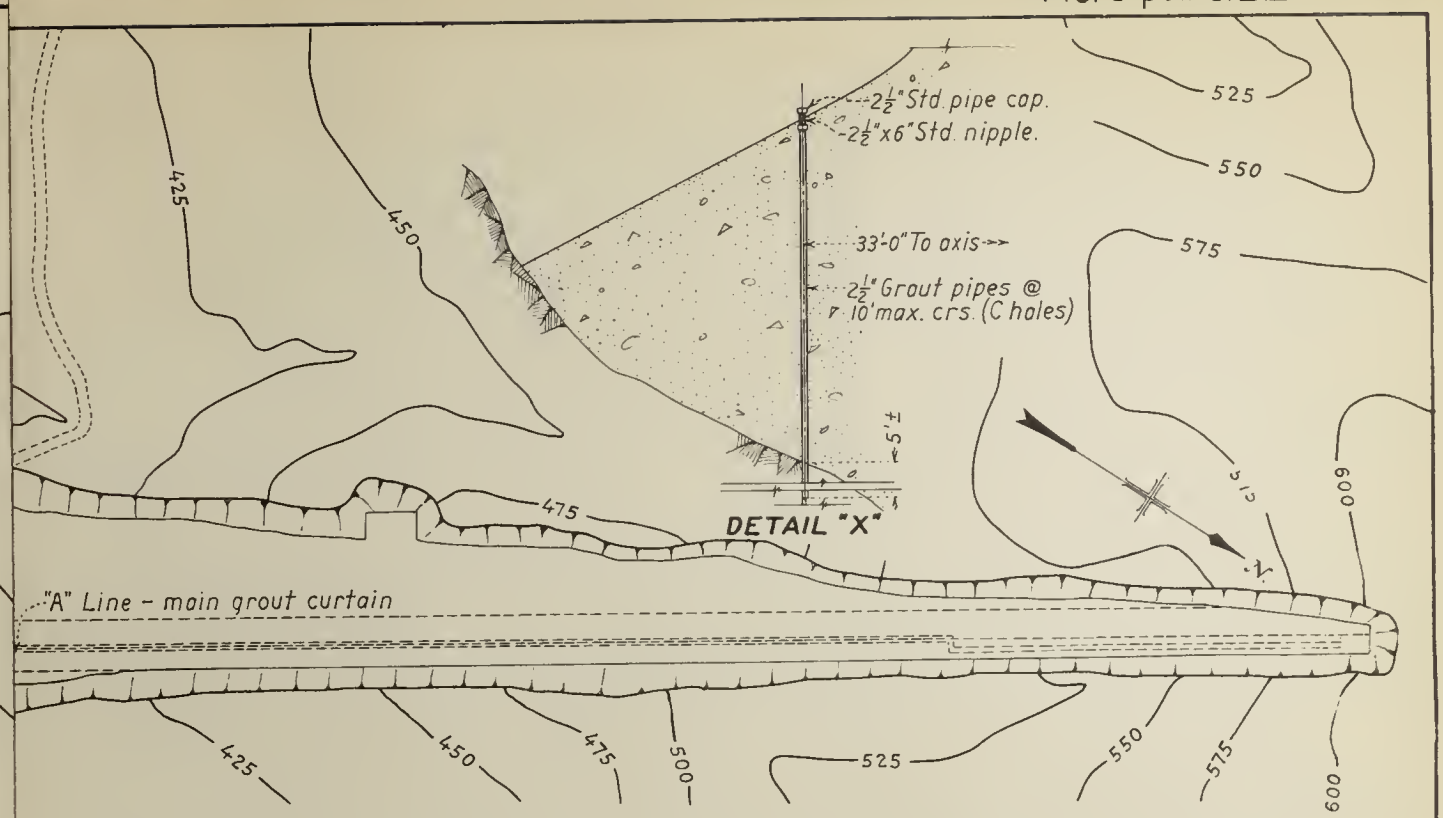
KORTES DAM

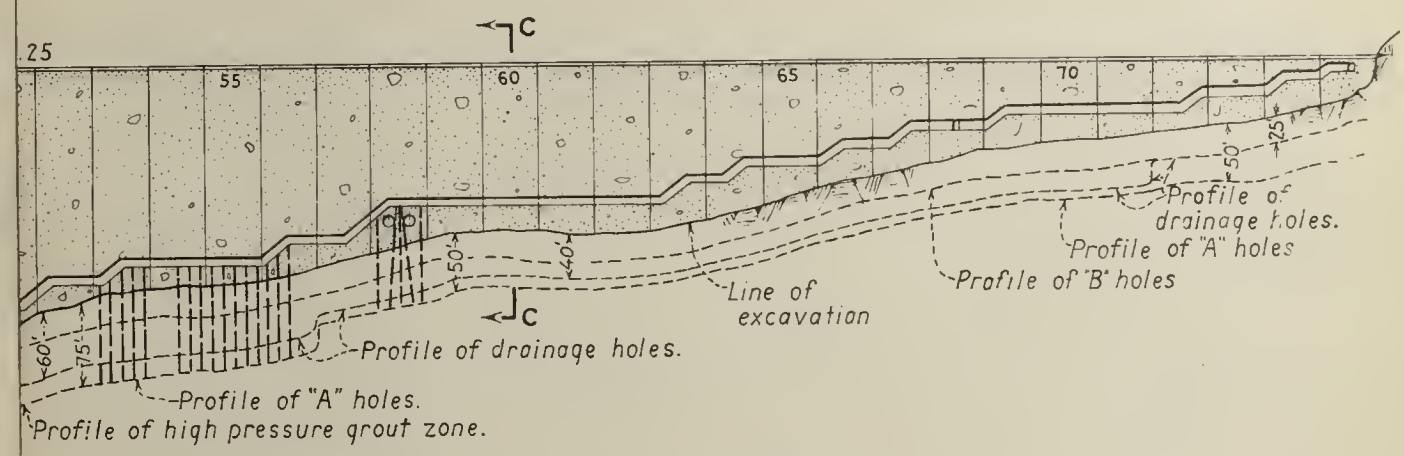
FOUNDATION GROUTING AND DRAINAGE

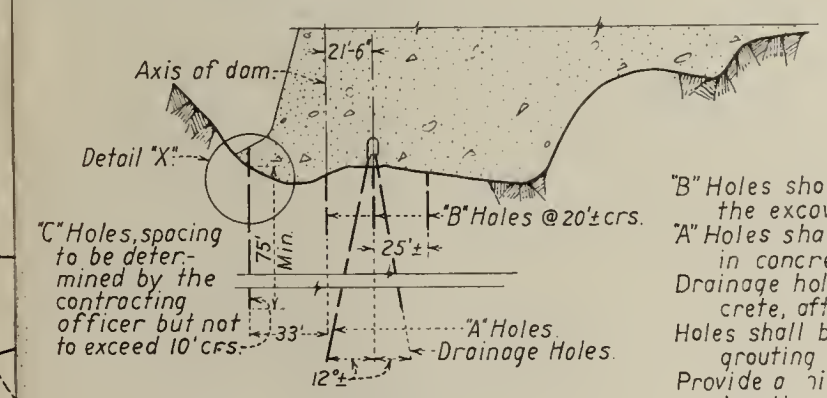
DRAWN	ATL	SUBMITTED	[illegible]
TRACED	ILA	RECOMMENDED	[illegible]
CHECKED	[illegible]	APPROVED	[illegible]
		DENVER, COLORADO	NOV. 20, 1961

144-D-360

FIG. 8 par. 5.2.21







SECTION D-D

NOTES

"B" Holes shall be drilled and grouted after completion of the excavation and prior to placing concrete.

"A" Holes shall be drilled and grouted thru pipes embedded in concrete.

Drainage holes shall be drilled thru pipes embedded in concrete, after completion of "A" and "C" hole grouting.

Holes shall be drilled at minimum diameters as follows: grouting holes $1\frac{3}{8}$" dia.; drainage holes 5" dia.

Provide a minimum clearance of 6" between pipes and contraction joints.

90°-4" Street elbow

6"x6"x4" Tee with c'ts'k. plug.

6" Drain pipe @ 10'± crs.

Calk tight

6" To 12"

GALLERY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT - CALIFORNIA
FRIANT DIVISION

FRIANT DAM

FOUNDATION GROUTING AND DRAINAGE

DRAWN: L.K.-A.F.S. SUBMITTED:
TRACED: J.J.B. RECOMMENDED:
CHECKED: APPROVED:

DENVER, COLORADO, MARCH 20 1939

214-D-639

REV. 1-17-41 H.E.S.
REV. 9-1-39 J.T.H.
7-9-42 A.F.S.
7-19-40 J.E.O. A.K.
10-14-40 J.E.O. A.T.M.

FIG. 8 par. 5.2.2.1

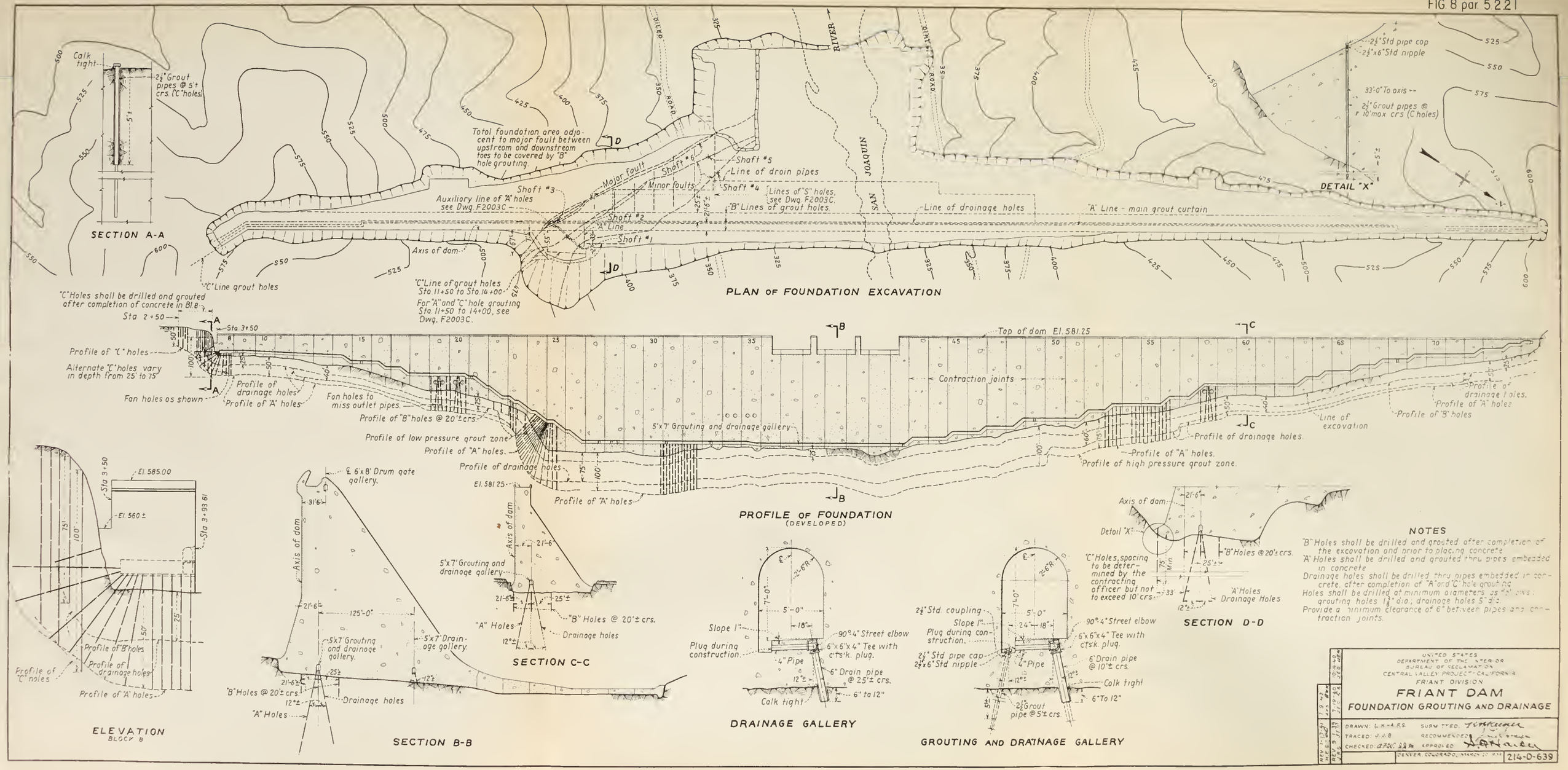
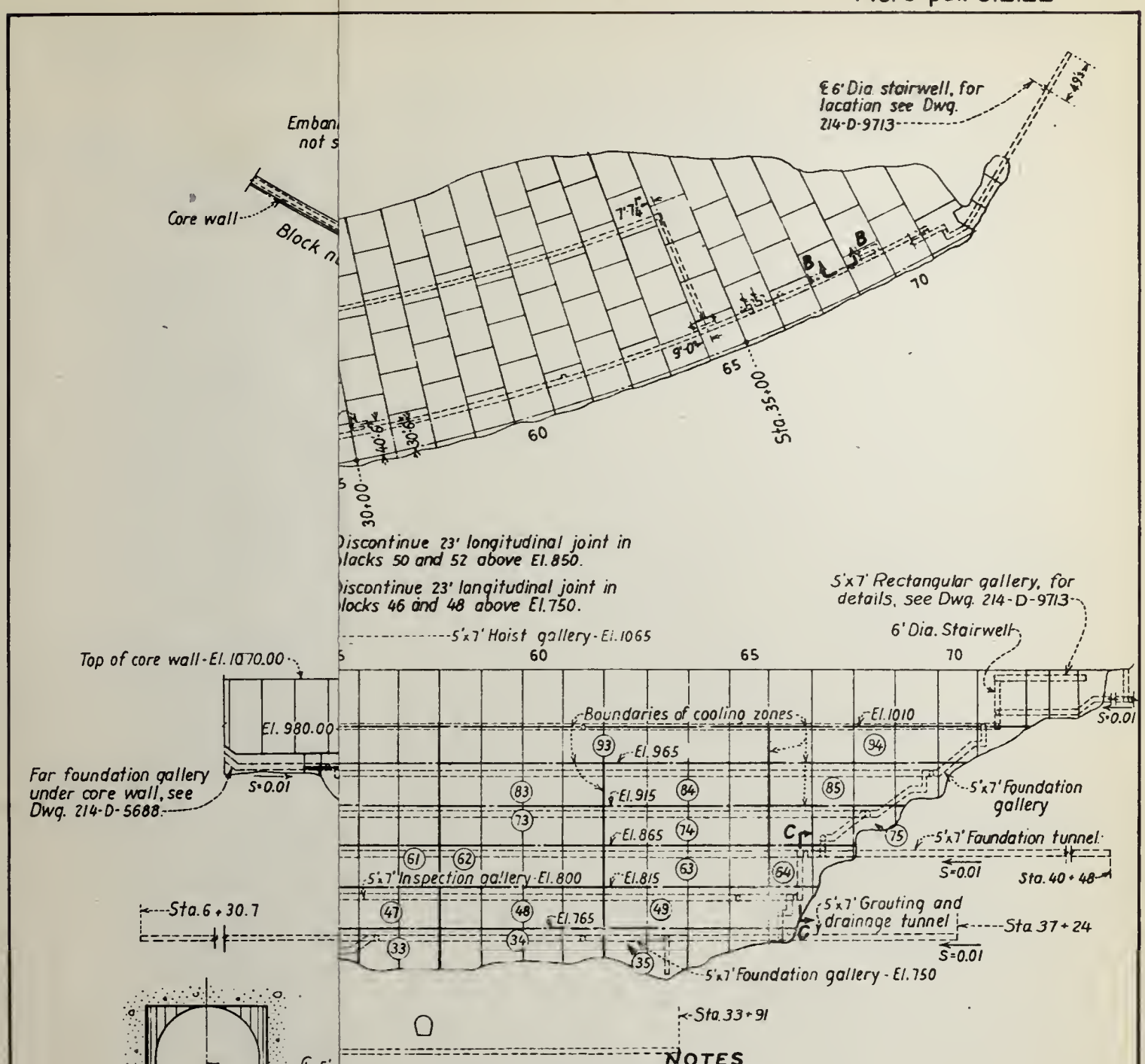
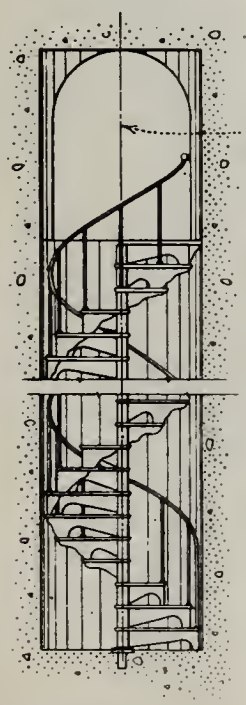


FIG. 9 par. 5.2.22





SECTION C-C

NOTES

Numbers in circles indicate cooling zones.
All stations are measured along axis.
All gate galleries except drum gate gallery are to contain tracks.
All galleries in abutments are to be constructed on chords between transverse contraction joints.
Distances from axis to ℄'s of galleries in abutments are to be measured along transverse contraction joints.
All longitudinal dimensions shown are on ℄ of gallery unless otherwise indicated.
Final position of foundation galleries will be determined by actual foundation conditions.
℄'s of 5x7 tunnels at El. 550 are to be located 14'-6" upstream from axis of dam; ℄'s of all other 5x7 tunnels shown, except those under core wall, are to be located 30'-6" downstream from axis of dam.

THIS DRAWING SUPERSEDES DWG. 214-D-717

REV. 10-22-41 P.B.R.	2-12-41 H.E.M.	REV. 4-17-40 H.E.M.	7-31-41 J.W.D.
11-7-44 W.F.		REV. 6-14-40 H.E.M.	9-17-40 H.E.M.
	10-17-41 H.E.M.		

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

CENTRAL VALLEY PROJECT - CALIFORNIA
KENNETT DIVISION

SHASTA DAM

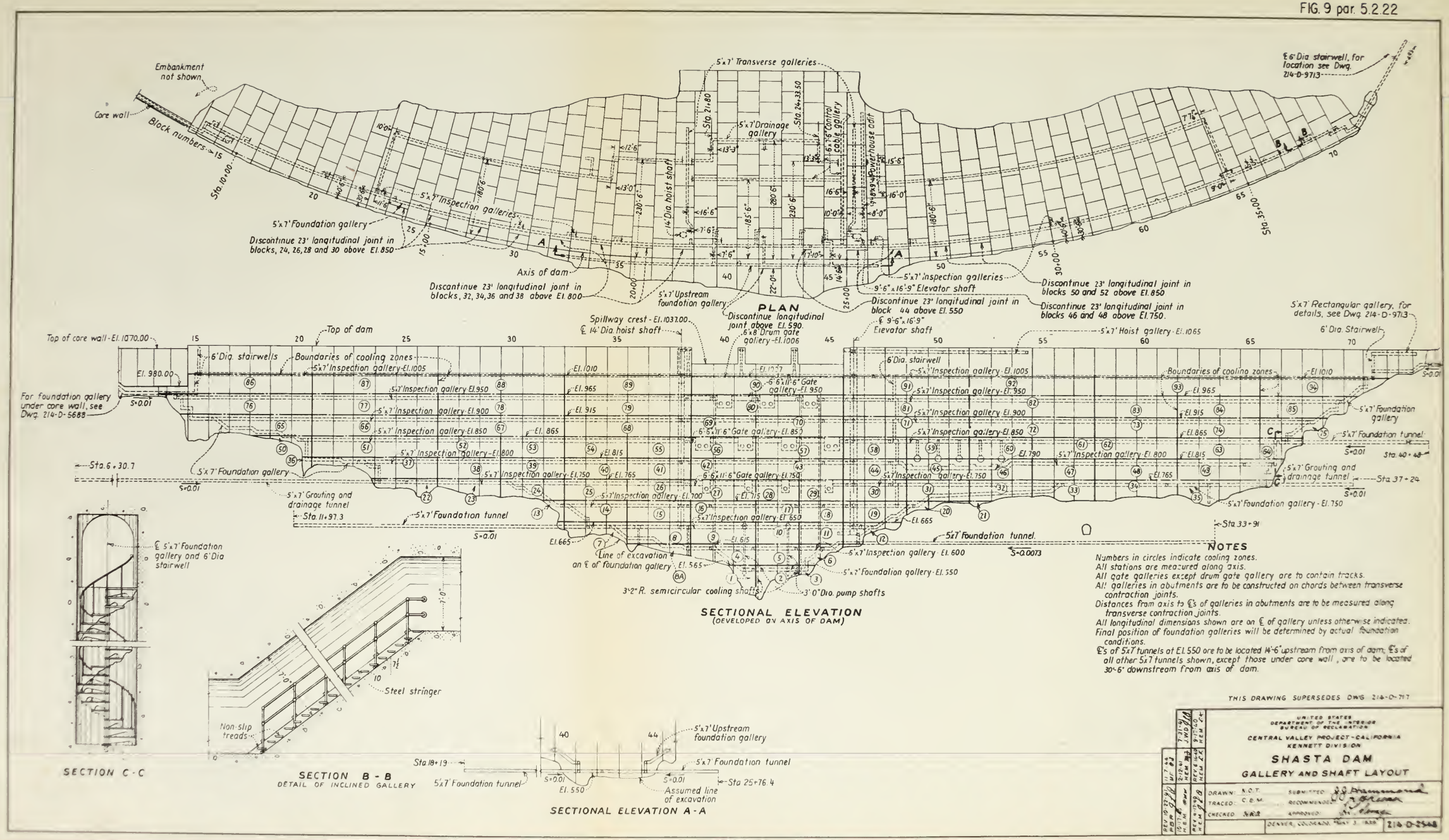
GALLERY AND SHAFT LAYOUT

DRAWN: K.O.T. SUBMITTED: J.J. Hammond
TRACED: C.E.M. RECOMMENDED: K.B. Keenan
CHECKED: H.R.O. APPROVED: J.L. Savage

DENVER, COLORADO, MAY 3, 1939.

214-D-2548

FIG. 9 par. 5.2.22



(.28)
provided at the entrances to prevent undesired air movements through the galleries and to keep out unauthorized persons.

SHAFTS

.29 Usually gravity dams require various vertical openings and shafts whose size, shape, and location depend upon the purpose for which they are used. The galleries are connected by circular stairway shafts usually 6 feet in diameter and by elevator or hoistshafts, or both, whose size is based on the size of service equipment they are to accommodate. Cooling shafts, in which headers of the artificial cooling system are located, are usually 3 feet 6 inches in diameter. One or more special shafts may be included for the purpose of accommodating measuring devices. A plumb-line shaft is usually located near the maximum section in order to make observations of the movements of the top of the dam with respect to the base. Special recesses are provided connecting this shaft with the galleries in order that observations may be made at various elevations. A stilling well is another special shaft which is sometimes included in the design of the dam. This shaft is open to the reservoir below minimum reservoir elevation and contains a float mechanism to record reservoir fluctuations.

REINFORCEMENT

.30 All the galleries, shafts, and other special openings in the dam interrupt the natural paths of stress in the structure and induce stress concentrations in the immediate vicinity of the openings sufficient to require steel reinforcement. The amount of reinforcement required is based on experimental determination of stress concentrations obtained by model tests and photoelastic studies as given in Technical Memoranda 451 and 555. Further requirements for reinforcement around circular openings, including temperature reinforcement, are given in Technical Memorandum 457. Minimum cover of 6 inches is usually specified from the surface to the centerline of reinforcing bars around galleries, shafts, and other openings in mass concrete. The spacing of bars is usually not less than 6 inches.

SPECIFICATION DRAWING OF GALLERIES

.31 An example of a specification drawing of a gallery and shaft system, illustrating the amount of detail required for such a drawing is given in Figure 9.

TEMPERATURE CONTROL

.32 Volume changes in concrete accompanying temperature variation produce crack-forming tendencies which must be controlled. The maximum volume change a dam will experience is produced by the change in temperature from the maximum to which the concrete will rise during the hardening period to the final stable temperature the structure will assume. During this period of adjustment, unless temperatures are controlled, the tensile stresses resulting from restraint

(.32) to free volume change and from the development of large temperature gradients throughout the mass may be greater than the concrete can withstand, and the concrete will crack in all directions. Such cracks destroy continuity and may affect the stability of the structure as well as detract from its appearance. The purpose of temperature control, therefore, is to prevent cracks by establishing more favorable temperature conditions than would otherwise exist. This is usually accomplished by preventing excess heat from being entrapped in the dam or by providing means for removal of such excess heat. The problem then becomes that of controlling design and construction operations in order to obtain the most favorable temperature conditions.

TEMPERATURE CONTROL (CONT.)

FACTORS AFFECTING TEMPERATURE

.33 A study of the more important factors which combine to produce the critical temperature condition will permit the selection of a method of control which is most effective at the least cost. These factors may be grouped under the following general headings: climatic conditions, composition of the concrete, design and construction methods, rate of construction, and character of the foundation.

CLIMATIC CONDITIONS

.34 Climatic conditions at the site include such factors as the temperature of the concrete at time of placing and conditions of exposure during construction, both of which can be controlled to a certain extent. Other climate factors such as exposure conditions after construction, final stable temperature of the concrete mass, and seasonal temperature variations, cannot be controlled. However, they must be studied and evaluated in order to determine temperature control methods which will conform to the final state of temperature equilibrium which the structure will attain.

PLACING TEMPERATURE

A. Reduction of the placing temperatures by reducing the temperatures of the concrete ingredients offers a method of temperature control by removal of excess heat before it is entrapped in the structure. The rate of heat generation at early age will also be reduced and thus will facilitate control of the temperature rise. An economical method of lowering the placing temperature is by the evaporative cooling effect of sprinkling the coarse aggregate just prior to use.

EXPOSURE

B. During construction, the top of the lifts, and often the sides, are exposed to temperatures equal to or lower than the placing temperature. The temperature within the block will rise almost adiabatically for

(.34B)

the first two days with the result that a steep temperature gradient with depth is developed through the lift. Optimum conditions for reduction of maximum temperature within the lift by exposure of the lift surface without development of excessive thermal stresses may be reached with an exposure of about 8 to 10 days. Further exposure will result in large temperature change of the top lift which, if the lift is restrained by the foundation or lift below, will be conducive to development of tensile cracks in the exposed surface.

EXPOSURE (CONT.)

.35 Composition of the concrete includes such factors as amount and type of cement used, type and character of the aggregate, thermal characteristics of the concrete, and physical properties of the concrete. The most important of these, and the one over which some control can be exercised, is the amount and type of cement. The other factors cannot be selected or controlled but are important in that they must be evaluated in order that an estimate can be made of the temperature behavior of the concrete.

COMPOSITION OF THE CONCRETE

The temperature rise of the concrete due to heat of hydration of the cement may be considered to vary directly with the cement content. Increasing the fineness of the cement increases the amount of heat developed at early ages by about the same percentage that the early strength is increased. The type of cement is also an effective factor since various types possess different heat generating properties. A lower maximum temperature of the concrete is obtained with a "low-heat" type of cement due to the slower rate of heat generation during the early age, since the rate of cooling will more quickly become equal to or can readily be made to equal the rate of heat generation.

AMOUNT AND TYPE OF CEMENT

.36 Design and construction methods include such factors as contraction joints and artificial cooling, both of which are very important and can be controlled. Other factors such as size and shape of section, forms and form removal, and water curing, have little effect on temperature control methods. Size and shape of section determines largely the time required for the concrete to reach temperature equilibrium without artificial cooling. Forms, form removal, and water curing affect the surface temperatures and should be studied in order to determine optimum temperature conditions at the surface consistent with construction requirements.

DESIGN AND CONSTRUCTION METHODS

(.36)

CONTRACTION JOINTS

A. Contraction joints are "formed cracks" which are provided at frequent intervals to relieve the tensile stress resulting from restrained contraction of the concrete and thus prevent uncontrolled cracking. For average conditions, with mass concrete, the spacing of contraction joints is usually 50 feet. However, greater spacing is feasible depending upon the degree of temperature control exercised. The temperature control will directly affect the joint openings and thus determine the time when joints should be grouted. Joint spacing and temperature control are therefore interdependent to a large extent.

ARTIFICIAL COOLING

B. Artificial cooling is definitely established as the most effective means of controlling the temperature of concrete. The most satisfactory, most flexible, and, for the degree of control obtained, the most economical method of artificially cooling the concrete is by circulating cold water through a pipe system embedded in the concrete. See Paragraph 5.2.39 for further discussion.

RATE OF CONSTRUCTION

.37 The rate of construction includes such factors as thickness of lifts, time interval between lifts, time of exposure of contraction joints, and seasonal limitations on placing concrete. Evaluation and study of these factors as to their affect on temperature control will permit the determination of the most favorable construction schedules.

THICKNESS OF LIFT

A. Reducing the vertical thickness of the lift tends to minimize the total temperature rise of the concrete by allowing more heat to be dissipated from the surface. The most satisfactory thickness, however, depends not only upon temperature control alone, but also upon economic considerations. The present, most commonly adopted thickness of 5 feet is a compromise and has proven very satisfactory. With this thickness and under usual conditions of the initial temperature of the concrete approximately equal to the average exposure temperature, a considerable portion of the total heat developed by hydration of the cement is lost from the top surface before the next lift is placed.

TIME INTERVAL BETWEEN LIFTS

B. In the interior of a large dam, the loss of heat from the surface of lifts is about the only loss occurring during construction. As soon as the lift is covered, practically no further loss occurs, and the temperature rises again due to continuing hydration of cement.

(.37B)

Peak temperature will usually be reached in a 5 foot lift in about three days after placing. Optimum conditions for the reduction of temperature by exposure of the surface of the lift without development of excessive thermal stresses may be reached in 8 to 10 days. Further exposure will result in excessive cooling on the lift by inducing a large temperature change with respect to the temperatures of the lower lifts and, if restrained by the lower lifts, a condition is developed which is conducive to the formation of tensile cracks in the exposed surface.

TIME INTERVAL BETWEEN LIFTS (CONT.)

C. If cracks are to be averted in the sides of blocks, the time of exposure at contraction joints should be limited to the minimum possible. Unless blocks are very small the loss of heat to the sides has little effect on the maximum temperature.

EXPOSURE OF CONTRACTION JOINTS

D. Construction of large structures usually extends over several seasons. It is desirable, from the temperature standpoint, that mass concrete be placed at the lowest possible air temperature consistent with insurance against freezing. Conversely, it is undersirable to place concrete in very hot weather. Measures of control, in addition to artificial cooling, can be exercised to reduce the ill effects of hot weather placement, such as precooling of aggregates and mixing water or the use of shallow lifts with longer interval between lifts.

SEASONAL LIMITATIONS

.38 Restraint to volume change in the concrete is quite high at the foundation contact. For best results the concrete temperature, at the time of placement, should be at or below the rock temperature, and increases in temperature in both concrete and rock should be kept to a minimum. Such changes as do occur should be made to take place over a long period of time. If the contact temperatures are prevented from changing materially, differences in thermal characteristics between rock and concrete are not important.

CHARACTER OF FOUNDATION

.39 In massive structures, artificial cooling of the concrete in combination with other expedients suggested in the preceding paragraphs offers the most effective means of controlling temperatures.

ARTIFICIAL COOLING

There are numerous advantages to be gained by cooling the concrete artificially and further advantages by using an embedded pipe system for the circulation of the cold water. The more important advantages are:

ADVANTAGES

(.39)

ADVANTAGES (CONT.)

A. The concrete may be cooled to the final stable temperature during the construction period, after which, with the dam at minimum volume and the contraction joints opened to the fullest extent, the joints may be grouted, making the dam the monolithic structure considered in the stress analysis.

B. The mass may be cooled uniformly, preventing the formation of large temperature gradients from the warm interior to the cold exterior conducive to cracking of the concrete at the exposed surfaces.

C. Subcooling may be accomplished if desired, and in the case of an arch dam with joints grouted in the subcooled condition, the effect of the subsequent temperature rise will counteract and prevent excessive deflection due to water load.

D. The temperature of the various parts of the structure may be controlled at the time of grouting the joints so that the effect of subsequent temperature change can be used to counteract unfavorable stress distribution due to load.

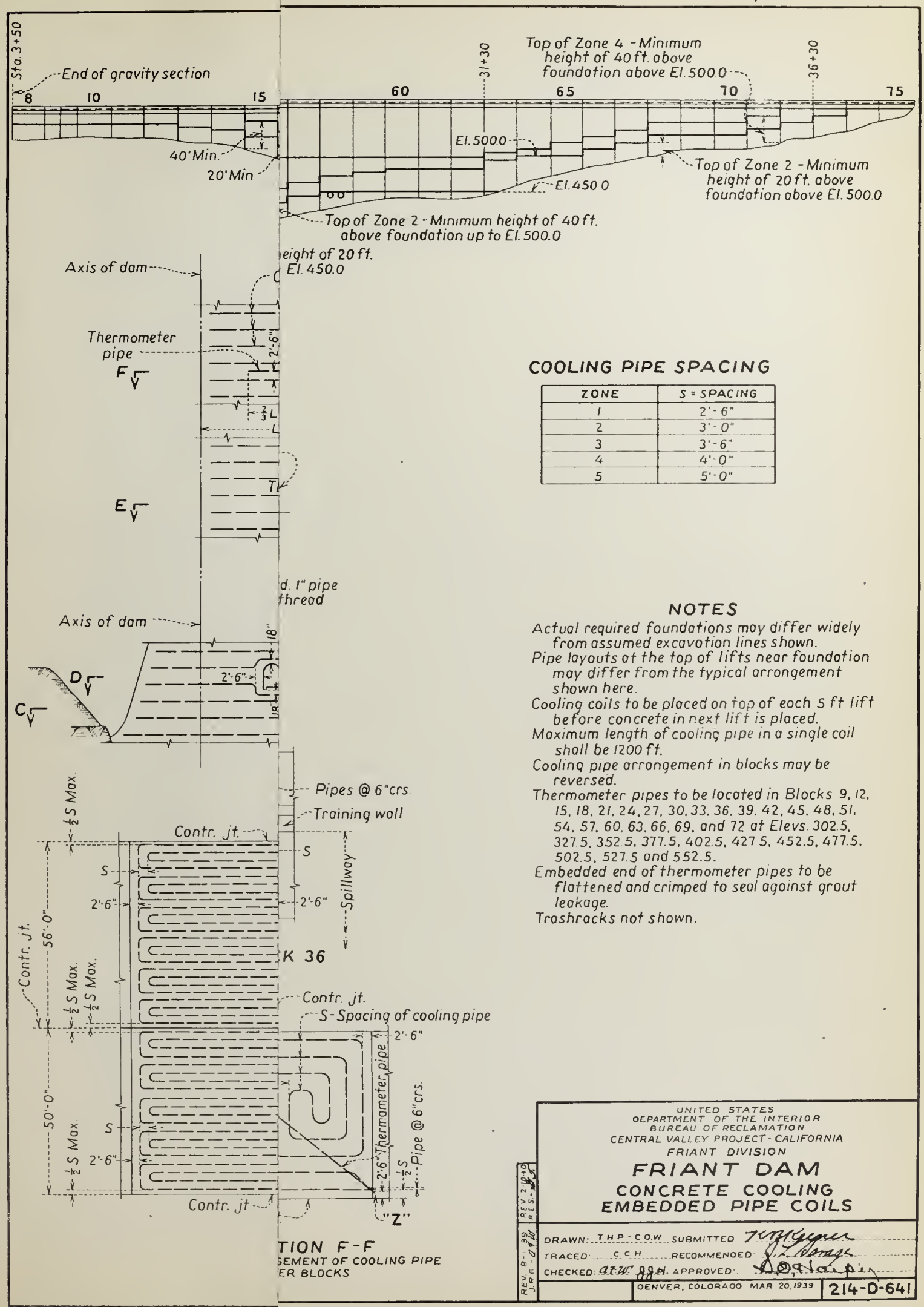
E. Artificial cooling started immediately after placing the concrete, especially with the use of cement which develops heat slowly, will lower the maximum temperature of the concrete considerably.

The use of the embedded pipe system affords flexibility in procedure of cooling and in operation of the system. Cooling may be accomplished from either face or from galleries or shafts within the dam. Any degree of cooling may be accomplished at any place at any time. The cost of cooling with an embedded pipe system is low. Complete cost of actual installations, including all labor and material cost chargeable to cooling, varied from $0.13 to $0.55 per cubic yard of concrete cooled.

COOLING SYSTEM

.40 The cooling system in most general use is made up of a number of embedded coils in parallel and served by supply and return headers. Each coil is made up of 1-inch outside diameter thin-wall metal tubing about 800 to 1200 feet long, coupled with expansion-type couplings. The tubing is placed on the top of each 5-foot lift of concrete after the concrete has hardened. The vertical spacing of the coils is thus 5 feet. The horizontal spacing of the tubes is varied to meet temperature

FIG. 10 par. 5.2.40



COOLING PIPE SPACING

ZONE	S = SPACING
1	2'-6"
2	3'-0"
3	3'-6"
4	4'-0"
5	5'-0"

NOTES

Actual required foundations may differ widely from assumed excavation lines shown.

Pipe layouts at the top of lifts near foundation may differ from the typical arrangement shown here.

Cooling coils to be placed on top of each 5 ft lift before concrete in next lift is placed.

Maximum length of cooling pipe in a single coil shall be 1200 ft.

Cooling pipe arrangement in blocks may be reversed.

Thermometer pipes to be located in Blocks 9, 12, 15, 18, 21, 24, 27, 30, 33, 36, 39, 42, 45, 48, 51, 54, 57, 60, 63, 66, 69, and 72 at Elevs. 302.5, 327.5, 352.5, 377.5, 402.5, 427.5, 452.5, 477.5, 502.5, 527.5 and 552.5.

Embedded end of thermometer pipes to be flattened and crimped to seal against grout leakage.

Trashracks not shown.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT - CALIFORNIA
FRIANT DIVISION

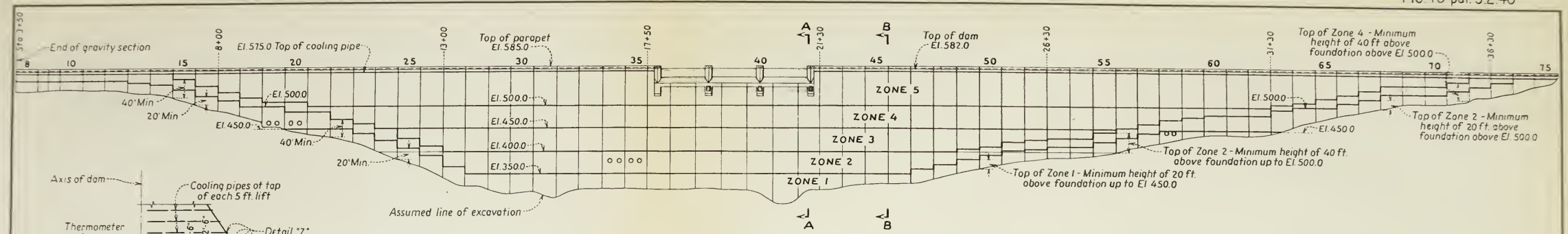
FRIANT DAM

CONCRETE COOLING EMBEDDED PIPE COILS

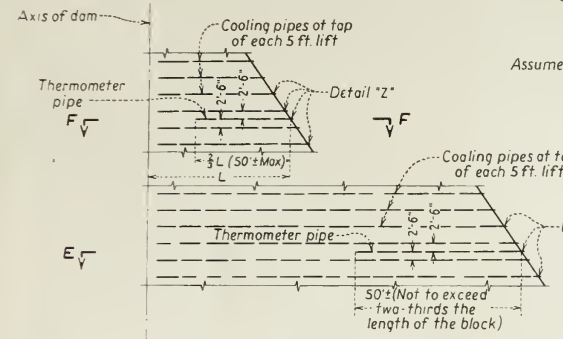
DRAWN: T.H.P. - C.O.W. SUBMITTED
TRACED: C.C.H. RECOMMENDED
CHECKED: APPROVED
DENVER, COLORADO MAR 20, 1939

214-D-641

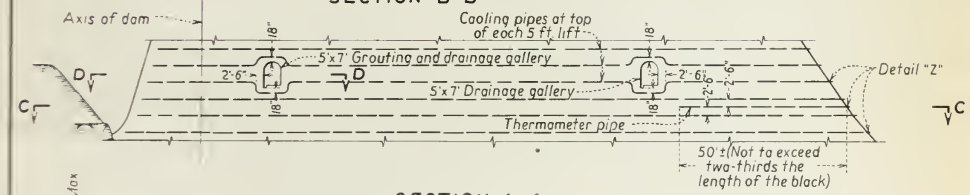
FIG. 10 par. 5.2.40



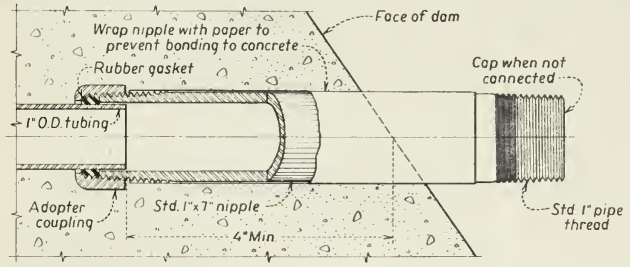
UPSTREAM ELEVATION



SECTION B-B



SECTION A-A



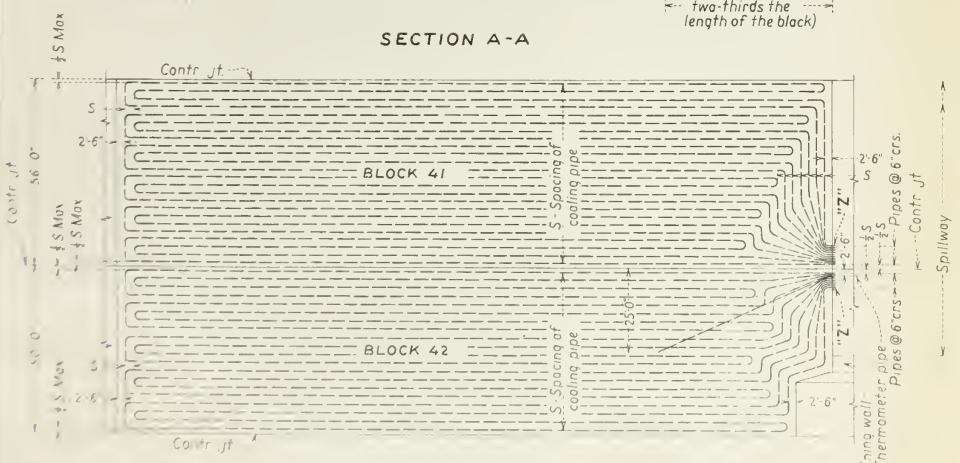
DETAIL "Z"
COOLING AND THERMOMETER PIPE OUTLET

COOLING PIPE SPACING

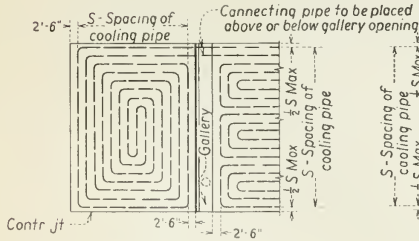
ZONE	S = SPACING
1	2'-6"
2	3'-0"
3	3'-6"
4	4'-0"
5	5'-0"

NOTES

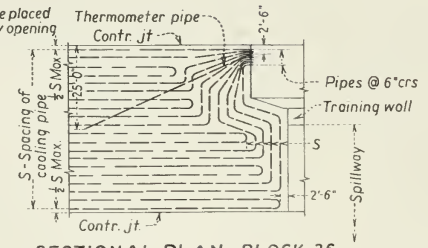
Actual required foundations may differ widely from assumed excavation lines shown.
Pipe layouts at the top of lifts near foundation may differ from the typical arrangement shown here.
Cooling coils to be placed on top of each 5 ft lift before concrete in next lift is placed.
Maximum length of cooling pipe in a single coil shall be 1200 ft.
Cooling pipe arrangement in blocks may be reversed.
Thermometer pipes to be located in Blocks 9, 12, 15, 18, 21, 24, 27, 30, 33, 36, 39, 42, 45, 48, 51, 54, 57, 60, 63, 66, 69, and 72 at Elevs 302.5, 327.5, 352.5, 377.5, 402.5, 427.5, 452.5, 477.5, 502.5, 527.5 and 552.5.
Embedded end of thermometer pipes to be flattened and crimped to seal against grout leakage.
Trashracks not shown.



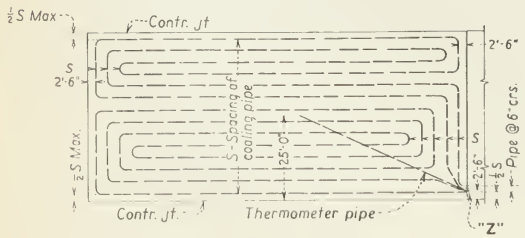
SECTION C-C
TYPICAL ARRANGEMENT OF COOLING PIPE
LOWER SPILLWAY BLOCKS



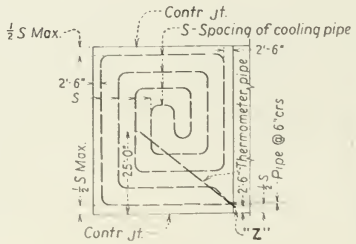
SECTION D-D
TYPICAL ARRANGEMENT OF COOLING PIPE AT GALLERY



SECTIONAL PLAN - BLOCK 36
BLOCK 42 OPPOSITE HAND



SECTION E-E
TYPICAL ARRANGEMENT OF COOLING PIPE
INTERMEDIATE BLOCKS



SECTION F-F
TYPICAL ARRANGEMENT OF COOLING PIPE
UPPER BLOCKS

UNITED STATES
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CENTRAL VALLEY PROJECT, CALIFORNIA
FRIANT DIVISION

FRIANT DAM
CONCRETE COOLING
EMBEDDED PIPE COILS

DRAWN THP-COW SUBMITTED
TRACED CCH RECOMMENDED
CHECKED APPROVED

DENVER, COLORADO MAR 20 1950 214-D-641

(.40) conditions, usually between two and six feet. The velocity of flow of the cooling water through the coils is not less than 2 feet per second, which amounts to about 4 gallons per minute for 1-inch tubing. The water is usually forced through the coils by pumps, though a gravity system may sometimes be used to advantage. When river water is used, the warmed water, after passing through the coils, is wasted. When refrigerated water is used, the warmed water is returned to the water coolers in the refrigerating plant and used repeatedly. The temperature of the concrete for control of the cooling-system operation is determined by resistance thermometers embedded in the concrete or inserted in pipes embedded in the concrete for that purpose. An example of the layout of an embedded pipe cooling system showing pertinent details required for a specification drawing is shown in Figure 10.

COOLING SYSTEM (CONT.)

.41 The factors entering into the design of a cooling system which affect economy, the rate of cooling, and the total time required for cooling are the size, spacing, and length of the embedded coils, the rate of circulation of cooling water, the thermal characteristics of the concrete, and the percentage of the total temperature differential between the warm concrete and the cold water that is required to be removed. The cooling rate is not greatly influenced by an increase in cooling pipe size, by reducing the length of coils, or by increasing the supply of cooling water. Computations of the effect of increasing the rate of flow through the 1-inch pipes indicate a marked improvement of performance up to a rate of 4 gallons per minute. Doubling the flow above 4 gallons per minute only decreases the time required for cooling some 20 to 25 percent for average conditions, whereas it doubles the capacity requirements, increases the friction losses, and more than doubles the power costs. The cooling rate may be effectively increased by decreasing the temperature of the cooling water or by adopting a closer pipe spacing.

DESIGN FACTORS

.42 The principal control of the operation of the cooling system is by observation of the temperature of the concrete. Temperatures can be obtained from resistance therometers embedded in the concrete or inserted in the cooling pipe system at locations which give representative values of concrete temperatures. The flow of water is measured at the pumps and can be regulated at many points in the system. With water flowing in the same direction continuously, the concrete at the head of the coil is cooled more than that near the end due to the increase in temperature of the water as it flows through the circuit.

CONTROL OF COOLING OPERATIONS

(.42) In practice, the headers serving the embedded coils are usually cross-connected or the hose connections from the inlet and outlet headers to the individual coils are manipulated so that the flow of water may be reversed at any time. In addition to equalizing cooling effects, this provision also offers a means of keeping the pipes from clogging, even with the use of turbid water.

BLOCK CONSTRUCTION

.43 In order to control the formation of cracks in massive concrete dams, it is the practice of the Bureau to provide transverse contraction joints at proper intervals. Depending upon the size of the structure, and other factors, it may also be necessary to provide joints in a longitudinal direction. The construction of the dam will then consist of placing a series of adjoining columnar blocks, each free to undergo its own volume change without restraint from the adjoining blocks as illustrated in Figure 11. Later, when the columns have assumed their final stable volume, the intervening joints are grouted so as to form one solid mass of concrete as contemplated in the design.

JOINTS AND NUMBERING

.44 All joints are vertical and usually pass completely through the structure. Transverse joints are normal to the axis and continuous from the upstream face to the downstream face. Longitudinal joints are parallel to the axis and offset at the transverse joints to form a longitudinal row of staggered columns. Each column or block is interlocked with adjacent blocks by vertical keys along transverse joints and horizontal keys along longitudinal joints. In order to simplify block identification, the blocks in each transverse row are usually designated by letter and each row by number.

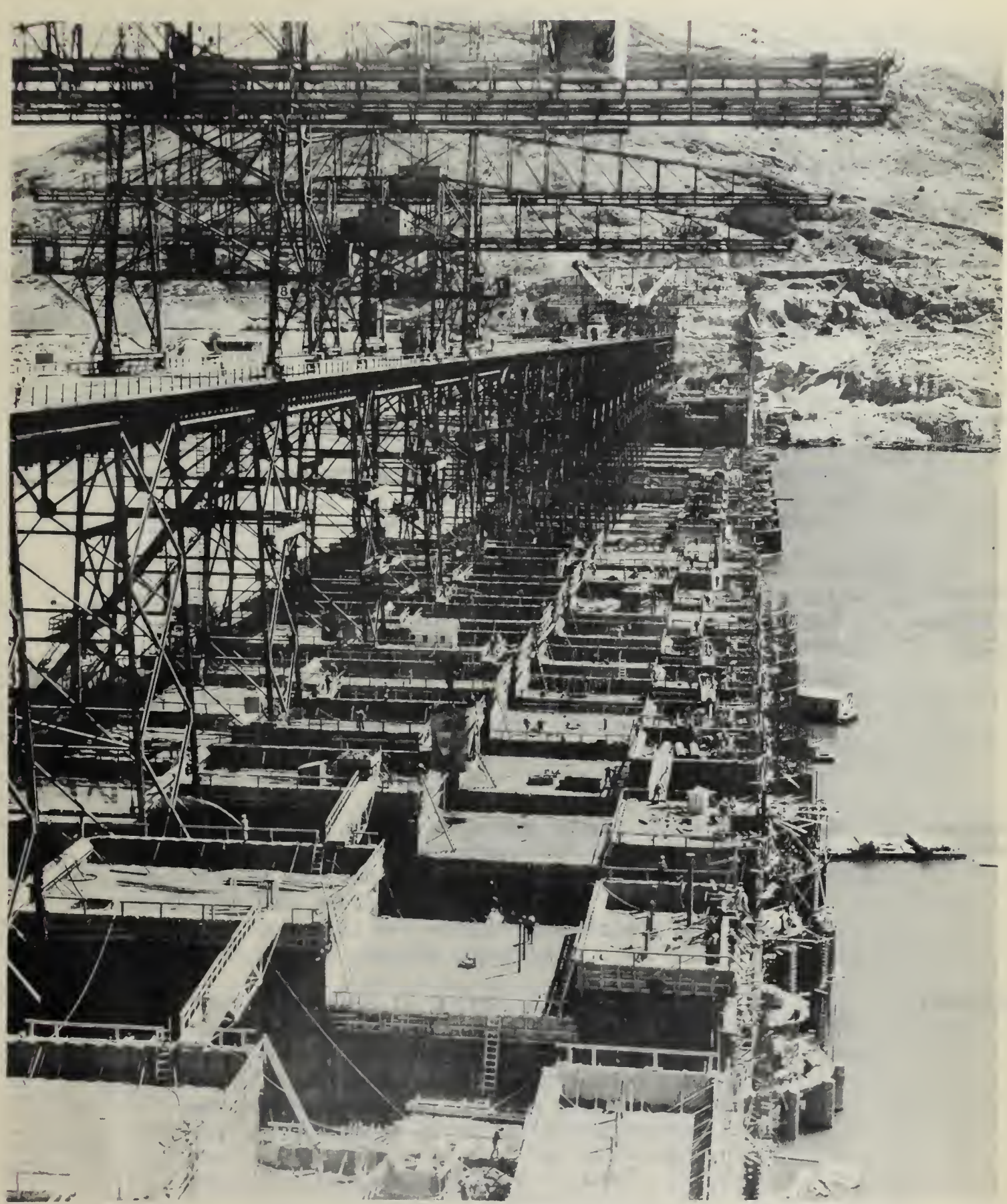
CONCRETE PLACING

.45 Concrete placing operations are regulated in order to conform with the requirements of the temperature control studies. The depth of each lift is restricted to 5 feet and the minimum elapsed time between placing operations on successive lifts in any one block restricted to 72 hours. Further restrictions are such that the maximum difference in elevation between any two blocks in the same row will not be greater than 15 feet and between any two blocks of adjacent rows will not be greater than 30 feet. The placing schedule is so planned that during the construction period the top of each block will maintain approximately a constant relative elevation with respect to adjacent blocks.

SURFACE CLEAN-UP

.46 The watertightness of the dam as a unit, assuming successful grouting of contraction joints, is dependent largely

FIG. 11 par. 5.2.43



BLOCK CONSTRUCTION AT GRAND COULEE DAM, WASHINGTON

(.46) on the thoroughness of clean-up operations between lifts and the bonding of the fresh to the old concrete at the horizontal construction joints. Before placing a new lift, the entire top surface of the old lift is thoroughly cleaned of laitance, coatings, stains, defective or fractured concrete, and all other foreign materials. This is best accomplished by wet sandblasting and washing. All excess water will then be removed from the surface, and immediately prior to placement of the new lift a thin layer of mortar, consisting of the regular concrete mix without the coarse aggregates, will be spread over the old concrete. SURFACE CLEAN-UP (CONT.)

.47 Conditions may arise which will require concrete of a richer mix to be placed at the upstream face or spillway surface. In the event this becomes necessary, the richer mix concrete and the adjacent mass concrete will be placed simultaneously so that the two mixes will unite in their plastic state to form an integral mass. CHANGE IN MIX

.48 As previously indicated, the purpose of contraction joints is to reduce random cracking by confining crack openings to predetermined planes. All transverse joints are normal to the axis of the dam and should pass completely through the dam for its full height. The edges formed at the intersections of the joints with the faces of the dam should be chamfered to give a desirable appearance and to minimize spalling. TRANSVERSE CONTRACTION JOINTS

.49 The spacing of transverse joints should be governed by a consideration of the following factors: physical features of the damsite, details of structures associated with the dam, results of temperature studies, and size of block that will not require excessive plant capacity for handling and placing concrete. SPACING FACTORS

A. Foundation defects and major irregularities in the rock are conducive to cracking; this sometimes can be prevented by judicious location of the joints. Cracks may also occur normal to the canyon wall. While it may not be practical to form inclined joints, consideration should be given to the canyon profile in spacing the joints so that the tendency for such cracks to form is kept to a minimum. FOUNDATION

B. Outlets, penstocks, spillway gates, or bridge piers at times control the location of joints and consequently their spacing. Due consideration should be given to the other factors, however, as it may be possible to ASSOCIATED STRUCTURES

(.49B)

relocate the associated structure, thereby securing a joint spacing more satisfactory to the dam as a whole.

TEMPERATURE CONTROL

C. Probably the most important consideration is the permissible spacing determined from the results of concrete temperature studies and the degree of temperature control to be exercised. If joints are too far apart, excessive shrinkage stresses will produce cracks in the block. On the other hand, if the joints are too close together, shrinkage may be so slight that the joints would not open far enough to permit efficient grouting.

PLANT CAPACITY

D. Contraction joints should be spaced close enough so that, with the plant capacity available, batches of concrete placed in the lift can always be covered while the concrete is still soft. For average conditions, a spacing of 50 feet has proved to be satisfactory. An effort is made to keep the spacing uniform throughout the dam in order that forms may be standardized and cost of forming and construction be held as low as possible.

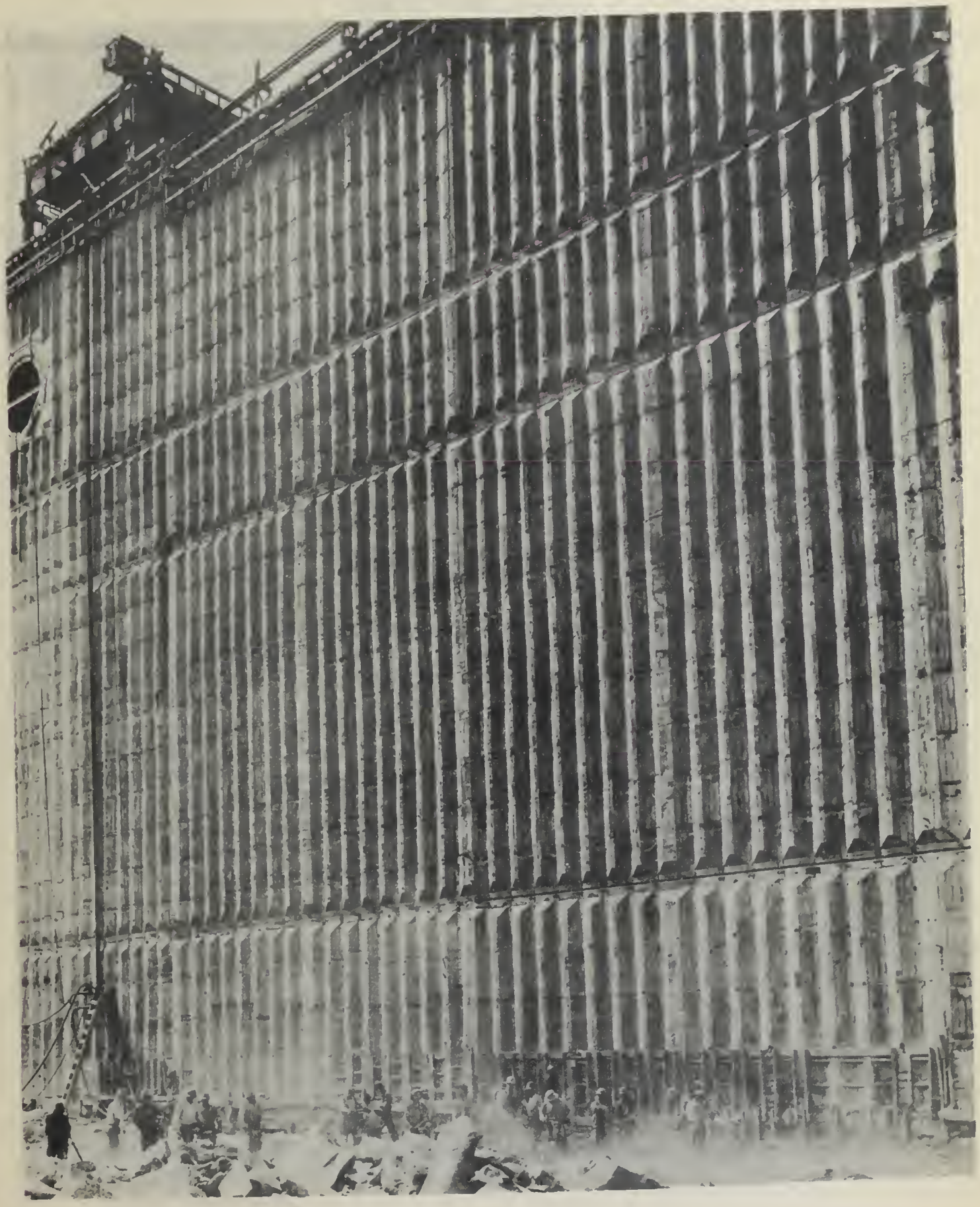
KEYS

.50 Keys in transverse joints serve two purposes: one, to minimize water leakage through the joints, and two, to provide shearing resistance at the joints. For relatively low gravity dams, the former purpose is probably the more important since the joints may not be grouted. Keys serve to increase the percolation distance through the joint, and by forming a series of constrictions, are beneficial in hastening the sealing of the joint with deposits. For relatively large dams employing additional means for controlling the flow of water through the joint, the second purpose becomes more important since the keys serve to interlock adjacent blocks thereby providing greater rigidity and stability.

BUREAU STANDARD

The joint keys developed by the Bureau for Boulder Dam have been standardized and are used in the construction of all solid concrete dams. The advantages of the standard keys over those of earlier design are many. The standard key offers the least obstruction to the flow of grout, provides a greater theoretical shear value, eliminates sharp corners which commonly cracked upon removal of forms, improves the reentrant angles conducive to crack development associated with volume changes, and is well adapted to the construction of forms. Figure 12 shows a view of formed keys on a typical transverse contraction joint. Exact shape and dimensions of the standard keys are shown in Figure 15.

FIG. 12 par. 5.2.50



TRANSVERSE JOINT OF GRAND COULEE DAM, WASHINGTON
SHOWING KEYS

.51 Drainage of the contraction joints is a desirable precaution against development of excessive pressure in the joint during the construction period and against seepage of reservoir water through the joints during the operating period. Where joint grouting systems are installed, the joint can be drained effectively during the construction period by opening the headers serving the grouting system. Effective grouting when the joints are opened to their widest extent may obviate any further need for drainage of the joint, and since provision of open drains makes effective grouting difficult, such drains have been omitted on many Bureau dams. However, where the additional precaution against seepage is desired, vertical drains on the joints are provided which will intercept water seeping through the joint and discharge such seepage water to the gallery drainage system preventing the unsightly and undesirable show of seepage on the downstream face. One form of drain that has been used is a formed circular vertical opening 5 inches in diameter, placed relatively close to the upstream face of the dam as illustrated in Figure 15. JOINT DRAINS

.52 As the height of a gravity dam increases, the base thickness approaches a limiting dimension beyond which a condition favorable to vertical cracking parallel to the axis is created. One means of preventing uncontrolled cracking in this direction is to provide longitudinal contraction joints. These joints are staggered at the transverse joints as discussed in Paragraph 44. Generally, the joints pass entirely through the structure, except in the upstream sections of dams with sloping upstream faces. Near the downstream face, the direction of the joint is changed from the vertical in order to effect a perpendicular intersection with the face. LONGITUDINAL CONTRACTION JOINTS

.53 The practice of spacing longitudinal joints follows in general that for transverse joints, the average spacing of 50 feet becoming standardized. Departures from this spacing often are desirable and necessary since the degree to which artificial temperature control can be exercised may permit a much greater spacing. The spacing near the downstream toe of the dam should be regulated to avoid toe blocks which are too short to permit adequate interlocking or too long to be reasonably safe from cracking depending upon the degree of temperature control to be exercised. SPACING

.54 It is undesirable to have a longitudinal joint intersect the upstream face. In order to avoid such practice, the joint is terminated at a minimum distance of 15 feet from TERMINATION OF JOINTS

(.54) the face. Special and careful treatment is required in order to prevent the joint from continuing as a crack in the higher lifts after construction. Despite the increased cost of artificial cooling to obtain a higher degree of control, it is desirable, and usually results in greater overall economy, to increase the joint spacing in the upstream sections thereby omitting joints requiring special attention.

DOWNSTREAM INTERSECTION

.55 In order to avoid feather edges and to improve the direction of joints with respect to spillway overflow, the vertical joints are turned so as to intersect the downstream face at right angles. Further exit treatment, to prevent corner spalling due to excessive stress transfer across the inclined joint during the period of relatively large volume change, consists of forming into the joint and leaving in place until joint grouting operations are under way a 1-1/2- to 2-inch light-weight wall board cushion approximately 24 inches deep. Before grouting the joint, this cushion is removed by air, water, and rake. After the joint is grouted the slot formed by the wallboard is dry-packed with cement mortar.

KEYS

.56 Shear keys are an important accessory in longitudinal joints and are provided to maintain stability of the dam by resistance to vertical shear. The key faces are inclined to make them conform approximately with the lines of principal stress for full water load. Inasmuch as the direction of principal stresses varies from upstream face to downstream face and from the foundation to the crest, an unlimited number of key shapes with resulting high forming costs would be required if close conformity were considered necessary. In order to simplify keyway forms, a single key shape, determined largely by the general direction of the lines of principal stress in the lower downstream portion of the dam where the vertical shear is maximum, has been adopted for standard use. Details of shape and dimensions are shown in Figure 16.

OPEN JOINTS

.57 Adverse conditions resulting from the unusual size of the structure, foundation defects, or temperature effects may be noted during the design or construction phases of the dam which can be overcome or reduced to safe proportions by the use of special open joints or slots during the construction period. Depending on their purpose, they may or may not be filled with concrete upon completion of the structure.

.58 Theoretical analyses and model tests of the stresses in high gravity dams indicate a concentration of twist effects in the abutment regions which is produced by the horizontal and vertical transfer of shear forces to the abutments. Under critical loading conditions, considerable tensile stresses may be built up, leading to the possibility of severe cracking. In order to relieve this situation, one or more twist slots may be placed in the steepest portions of the abutment sections as was provided at Grand Coulee Dam. Each slot is approximately 6 feet wide and extends from the base completely through the structure. During construction they were bulkheaded at the upstream and downstream faces and filled with sand in order to give lateral stability to the blocks and at the same time prevent the transfer of shear between adjacent blocks. Later, when the structure was subjected to its water load, thereby assuming its deflected position without the accompanying twist concentrations at the abutment, the sand in the slots was pumped out and replaced with concrete.

TWIST SLOTS

.59 When a dam is constructed over a fault zone, special precautions will be required, particularly if future movement of the foundation is anticipated, as in regions subject to earthquakes. A means of allowing unequal vertical and horizontal movements to occur at the fault without producing shear forces in the dam may be provided by placing over the fault zone an open joint which extends completely through the dam. Special keys in the upstream portion of the slot, shaped to allow movement in the anticipated direction, are incorporated in the design in order to distribute to the adjacent blocks the water load acting on the projected area of the joint and to aid in securing an adequate water seal.

SHEAR SLOTS

.60 The use of temperature control slots or closing plugs is usually applicable to arch and arch-gravity dams only. In order to obtain suitable stress conditions in the completed arches, temperature control slots 2 to 4 feet wide may be left in the dam during construction. Closure is affected at a time of favorable temperature conditions, usually at the coldest season during the construction period when the adjacent blocks are at minimum volume. In this manner, after the structure is placed in operation, tensile stresses in the arches due to seasonal temperature variations may be practically eliminated.

TEMPERATURE CONTROL SLOTS

.61 The contraction of the construction blocks, accompanied by the opening of the contraction joints, provides passages

SEALS

(.61)
through the dam which, unless sealed, permit the leakage of water from the reservoir to the downstream face. To prevent this leakage, seals consisting of metal strips, asphalt, or rubber, are installed in the joint adjacent to the upstream face. Seals are also required for grouting operations in order to confine the fluid grout to a particular area. Figure 13 illustrates typical seals used in contraction joints.

METAL SEALS

A. The most common type of seal consists of variously shaped metal strips embedded in the concrete on both sides of the joint. They are similar in design whether used as water or grout seals but may differ as to type of metal. Bureau practice has standardized two shapes--Z-type and M-type.

Z-TYPE

(1) The Z-type shape is of simpler design, more easily installed, more easily spliced, but is capable of yielding but very little to block movements. Such a seal is well adapted to joints which are to be grouted, since grouting tends to consolidate the two blocks, thereby restricting movements.

M-TYPE

(2) The M-type seal is more difficult to splice but its shape permits accommodation to greater movement of the joint. This shape is well adapted for use as a water seal in ungrouted joints.

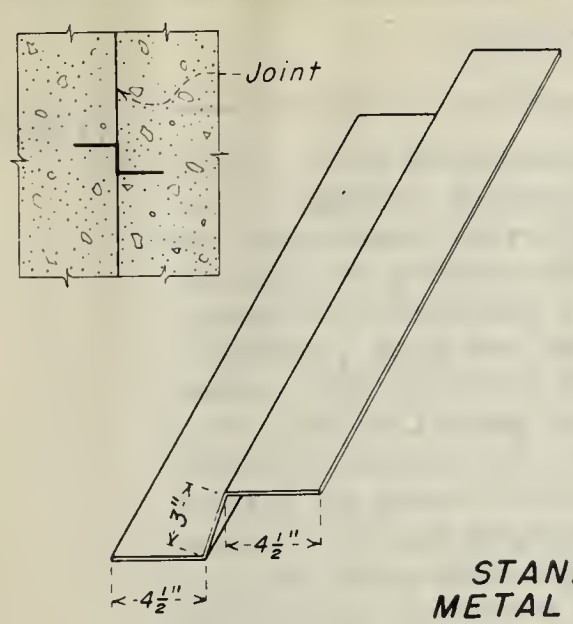
WORKMANSHIP

(3) From the standpoint of securing joint seals which are tight to begin with, the proper conduct of field operations is of greater importance than shape or material. Good workmanship in making connections; adequate protection to keep them from becoming wrinkled, torn, or punctured; detection and repair of all ruptures; and careful placement and consolidation of concrete around the seal are the principal safeguards against subsequent leakage.

ASPHALT

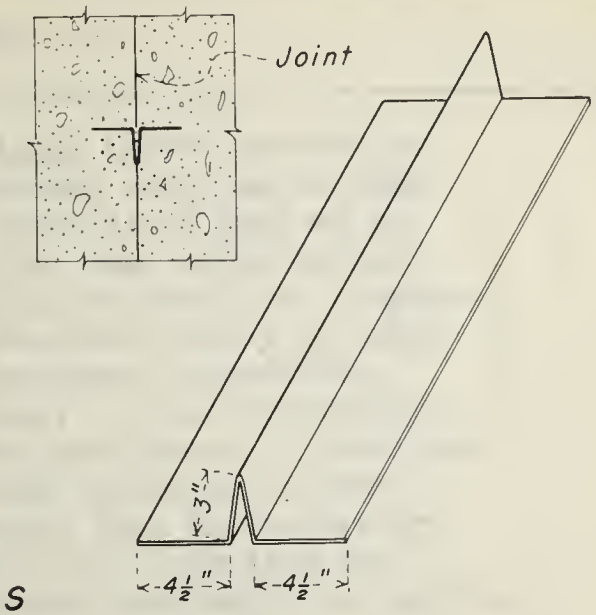
B. The asphalt water seal is constructed by forming a well of square or circular horizontal section across the contraction joint and filling with an asphaltic compound. The well is fitted in advance with a steam pipe or an electrical heat conductor for reliquefying the asphalt at such times as the opening of the joint or other conditions may require. Bureau experience has indicated the advisability of providing auxiliary metal seals across the joint on both sides of the asphalt seal to prevent leakage of asphalt through the joint to exposed surfaces.

FIG. 13 par. 5.2.61

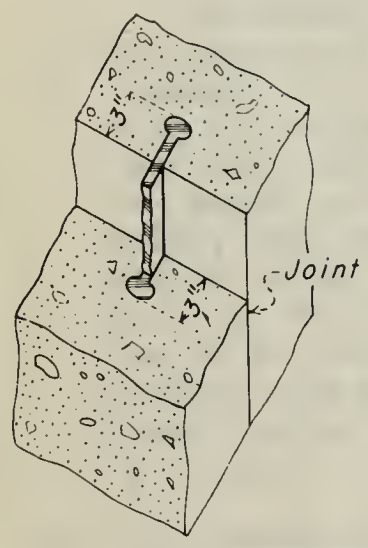


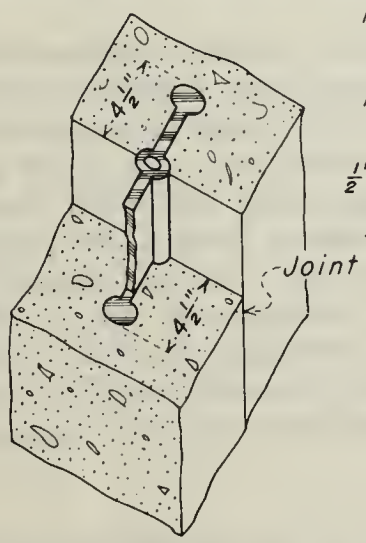
Z - TYPE

STANDARD METAL SEALS

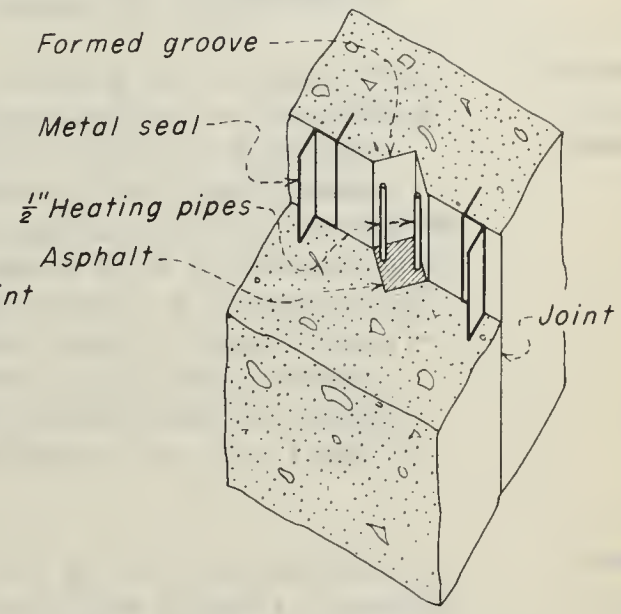


M - TYPE

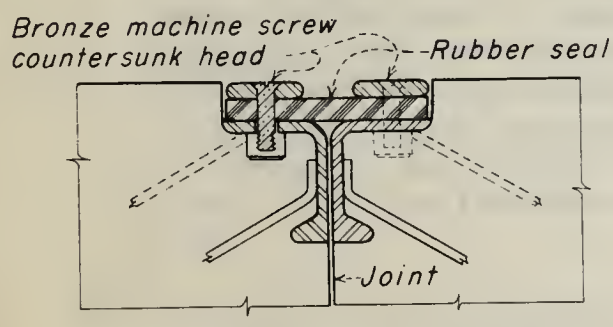




RUBBER SEALS



ASPHALT SEAL



FLEXIBLE SURFACE SEAL

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

TYPICAL SEALS FOR CONTRACTION JOINTS

BY. GRR	MAY 6, 1946
APV. CR	MD-DT-4

(.61)

C. Rubber seals have been developed by the Bureau for use in special joints in concrete sections of dams and appurtenant structures where it is desired to provide for greater movement at the joint, without appreciable transfer of stress or sacrifice in water-tightness, than can be accommodated safely by metal seals. Rubber seals have been used successfully under the following conditions: in the contraction joints between piers and the cantilevers of drum gate crests, to permit unrestrained deflection of the cantilevers and prevent leakage from the reservoir into the drum gate chamber; in the expansion and contraction joints of thin cantilever walls in stilling basins, to prevent objectionable leakage caused by unequal deflection and settlement of the walls; and in ungrouted contraction joints of some diversion dams, to prevent excessive leakage caused by differential settlement.

RUBBER

.62 The purpose of contraction joint grouting is to bind the construction blocks together so that the entire structure will act as one continuous mass. In order to approach this condition, a thin grout mixture of Portland cement and water is forced into the joint under suitable pressure which, upon setting, will form a dense film of cement well bonded to the adjacent blocks. The means of introducing grout to the joint is by an embedded pipe system consisting of 1-1/2-inch to 2-inch diameter supply and return headers from which 1/2-inch branch pipes lead to outlet units, called buttons, spaced uniformly over the face of the joint.

CONTRACTION JOINT GROUTING

.63 In order to insure complete grouting of the contraction joint before the grout begins to set, the joint is grouted in sections 50 feet in height. Thus a grout lift in a transverse joint consists normally of an area bounded on the sides by grout seals adjacent to the upstream and downstream faces of the dam, and above and below by grout seals 50 feet apart. Since the longitudinal joints are staggered, the grouting area of such a joint is normally bounded by vertical seals placed close to the adjacent transverse joints and horizontal seals placed at 50-foot intervals in elevation. Usually several such longitudinal grout lifts are interconnected by piping to form a grout zone.

GROUT LIFTS

.64 The layout of the piping system for transverse joints is illustrated in Figures 14 and 15. A horizontal 1-1/2-inch or 2-inch looped supply-and-return header is embedded in the concrete adjacent to the lower boundary of the lift. One-half inch embedded vertical risers take off

TRANSVERSE JOINTS

TRANSVERSE JOINTS (CONT.)

(.64) from the supply header at 6- to 7-foot intervals and terminate near the top of the lift or near the downstream face of the dam. Grout outlets are connected to the risers at 5- to 10-foot staggered intervals to insure complete coverage of the joint. The looped supply-and-return header permits the delivery of grout to the various 1/2-half inch distribution pipes from either or both ends of the headers, as may be desired, and therefore provides greater assurance that grout will be admitted to all parts of the joint area. The top of each grout lift is vented to provide for the escape of air, water, and thin grout which rises in the joint as grouting proceeds. This vent consists of a triangular groove formed in the face of the high block and is covered with a 20-gage metal plate which serves as a form for the concrete in the adjacent block. Vent pipes are connected to each end of the groove and extend to the grouting gallery or to the downstream face of the dam, thereby forming a vent open at both ends which will continue to function if an obstruction is formed at any one point.

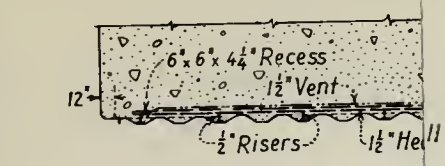
LONGITUDINAL JOINTS

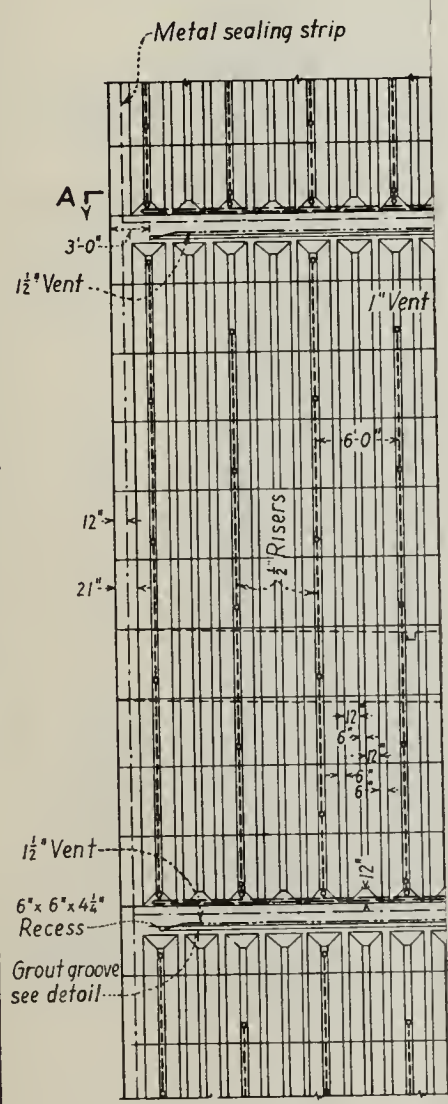
.65 The piping arrangement for longitudinal joints is somewhat different, as illustrated in Figure 16. A horizontal 1-1/2-inch or 2-inch looped supply-and-return header running normal to the axis of the dam is connected to the piping system of each of the longitudinal joints at one of the lower corners of the grout lift. At each such intersection, a 1-inch riser takes off from the header and extends to nearly the top of the lift. One-half inch distribution pipes are connected to this riser at 5-foot intervals and run horizontally to the other side of the joint where they connect with a second 1-inch return riser which in turn connects at the bottom with a 1-inch or a 1-1/2-inch return line. Grout outlets are attached to the horizontal distribution pipes at approximately 10-foot intervals. The return line, which parallels the supply header, aids in the release of entrapped air and water in the system, and may be used for grouting the joint in the event the supply header becomes plugged. As in the case of transverse joints, vent grooves are provided at the top of each lift which are connected at each end with a 1-1/2-inch vent pipe leading to the grouting galleries or to the downstream face.

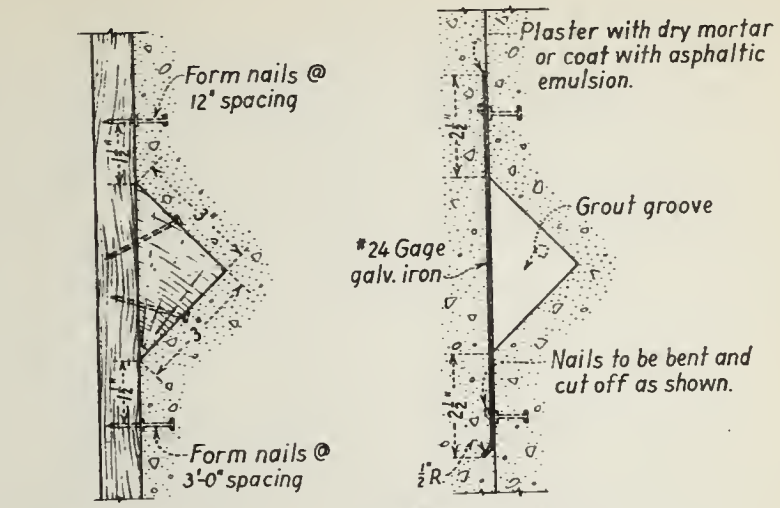
TERMINATION OF HEADERS

.66 The location of the inlet and outlet ends of the supply-and-return headers varies with conditions. In massive-gravity and arch-gravity dams, the headers are usually arranged to terminate in galleries, whereas in dams designed without galleries, the headers terminate at the

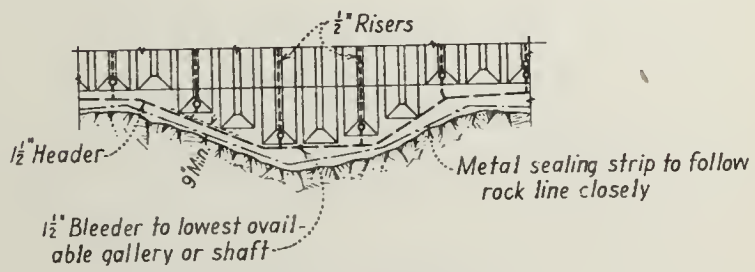
FIG. 14 par. 5.2.64







DETAIL OF GROOVE



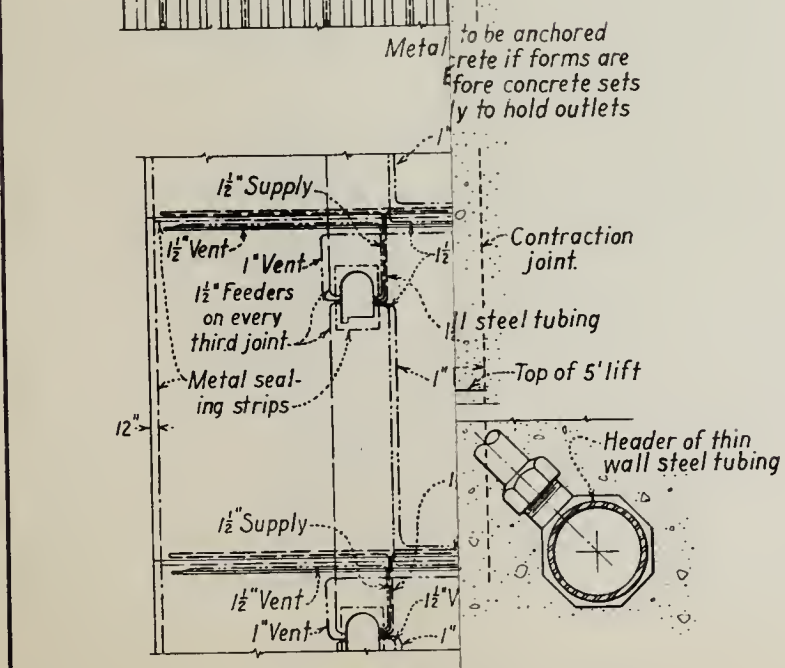
TYPICAL DETAIL OF JOINT AT
LOWEST ELEVATION

EXPLANATION

Supply, header, and return line
Riser vent
Vent header, vent, and vent return
Feeder
Metal sealing strip
Grout groove

NOTES

All contraction joint keys shall project out from high block joint plane.
Metal sealing strips shall be placed across all contraction joints as near bedrock as possible.
Always place headers and outlets in the block with the higher elevation.
All headers to be self draining wherever possible.



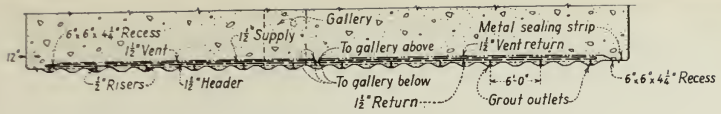
TYPICAL TLET DETAIL

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DENVER OFFICE

TRANSVERSE CONTRACTION JOINTS
KEYWAYS AND GROUTING SYSTEM
GROUTING FROM GALLERIES

DRAWN A.O. SUBMITTED
TRACED R.E.B. RECOMMENDED
CHECKED APPROVED
CHIEF ENGINEER
DENVER, COLORADO. NOV. 20, 1945 | 140-D-3815

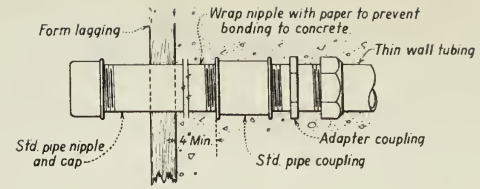
FIG. 14 par. 5.2.64



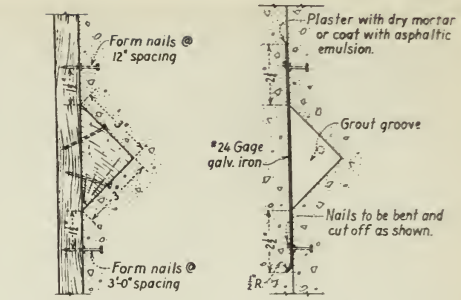
SECTION A-A

MINIMUM RADIUS BENDS FOR THIN WALL STEEL TUBING

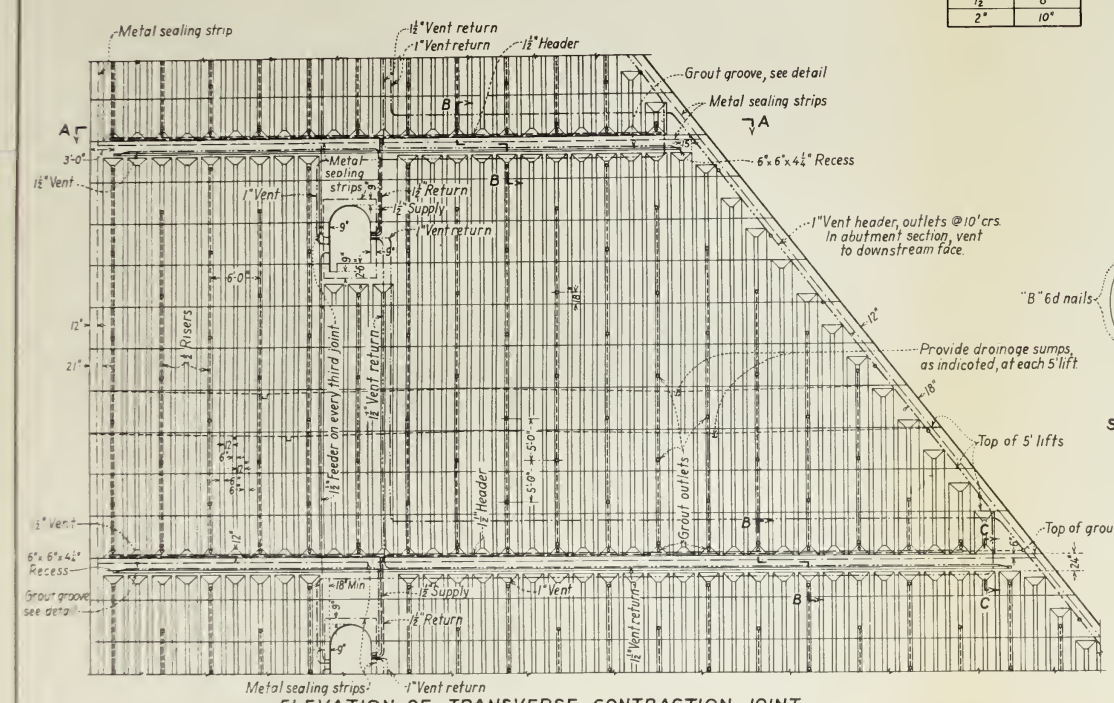
SIZE OF TUBING	RADIUS OF BENDS
½"	3"
1"	5"
1½"	8"
2"	10"



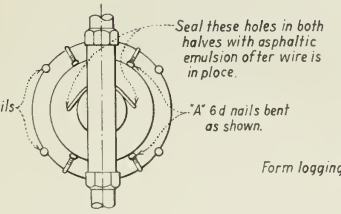
DETAIL OF SURFACE CONNECTION



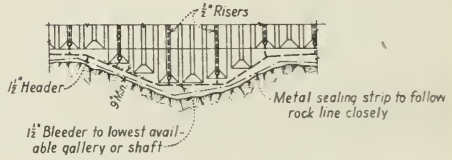
DETAIL OF GROOVE



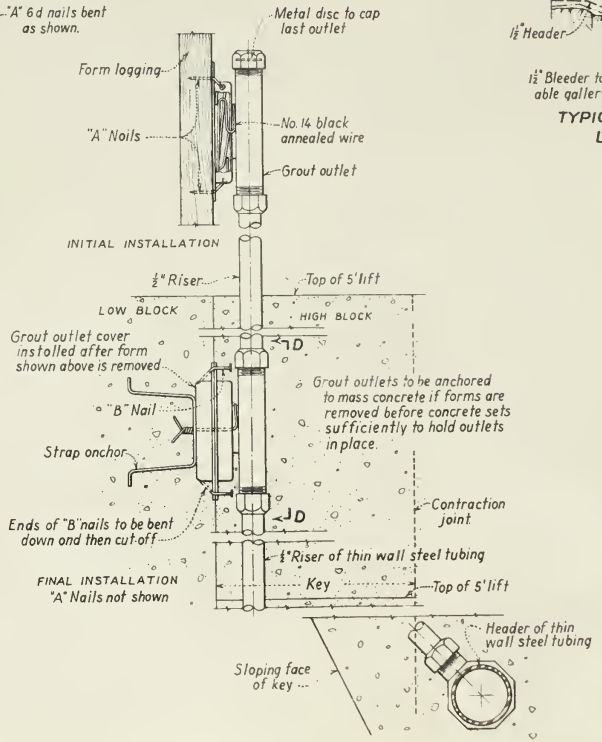
ELEVATION OF TRANSVERSE CONTRACTION JOINT



SECTION D-D



TYPICAL DETAIL OF JOINT AT LOWEST ELEVATION



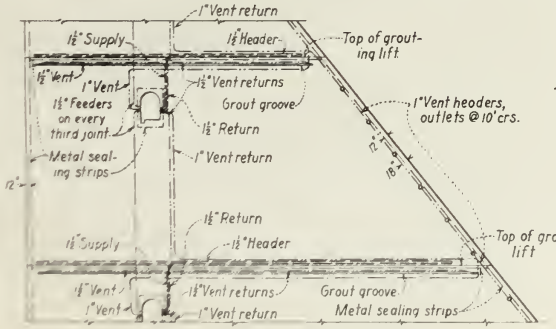
GROUT TUBING AND OUTLET DETAIL

EXPLANATION

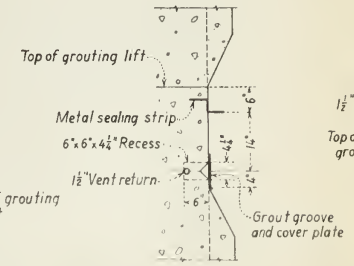
- Supply, header, and return line
- Riser vent
- Vent header, vent, and vent return
- Feeder
- Metal sealing strip
- Grout groove

NOTES

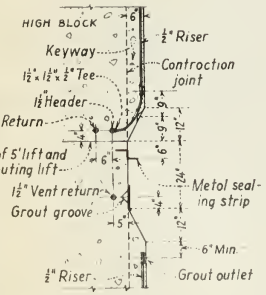
All contraction joint keys shall project out from high block joint plane.
Metal sealing strips shall be placed across all contraction joints as near bedrock as possible.
Always place headers and outlets in the block with the higher elevation.
All headers to be self draining wherever possible.



TYPICAL TRANSVERSE JOINT



SECTION C-C



SECTION B-B

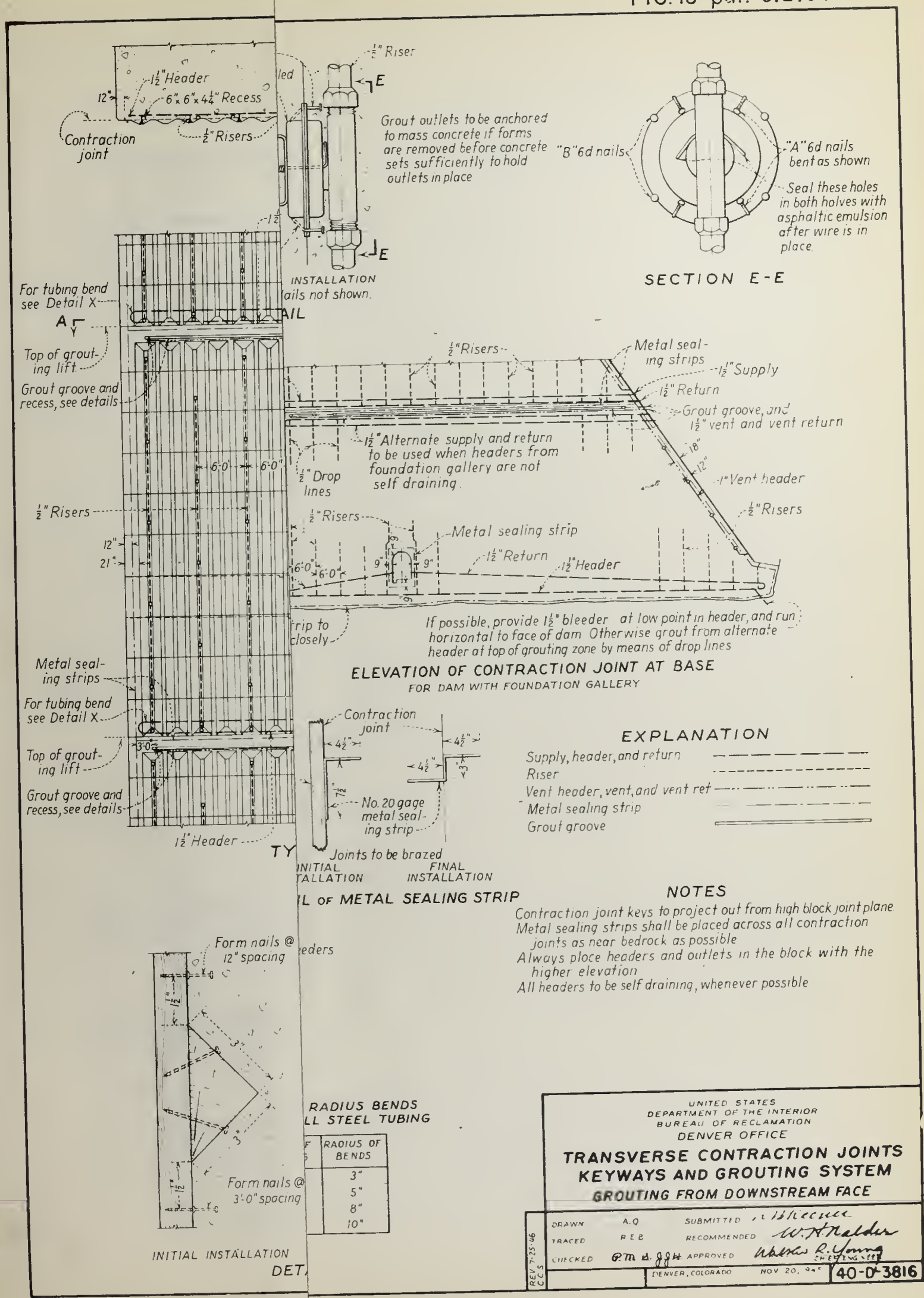
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DENVER OFFICE

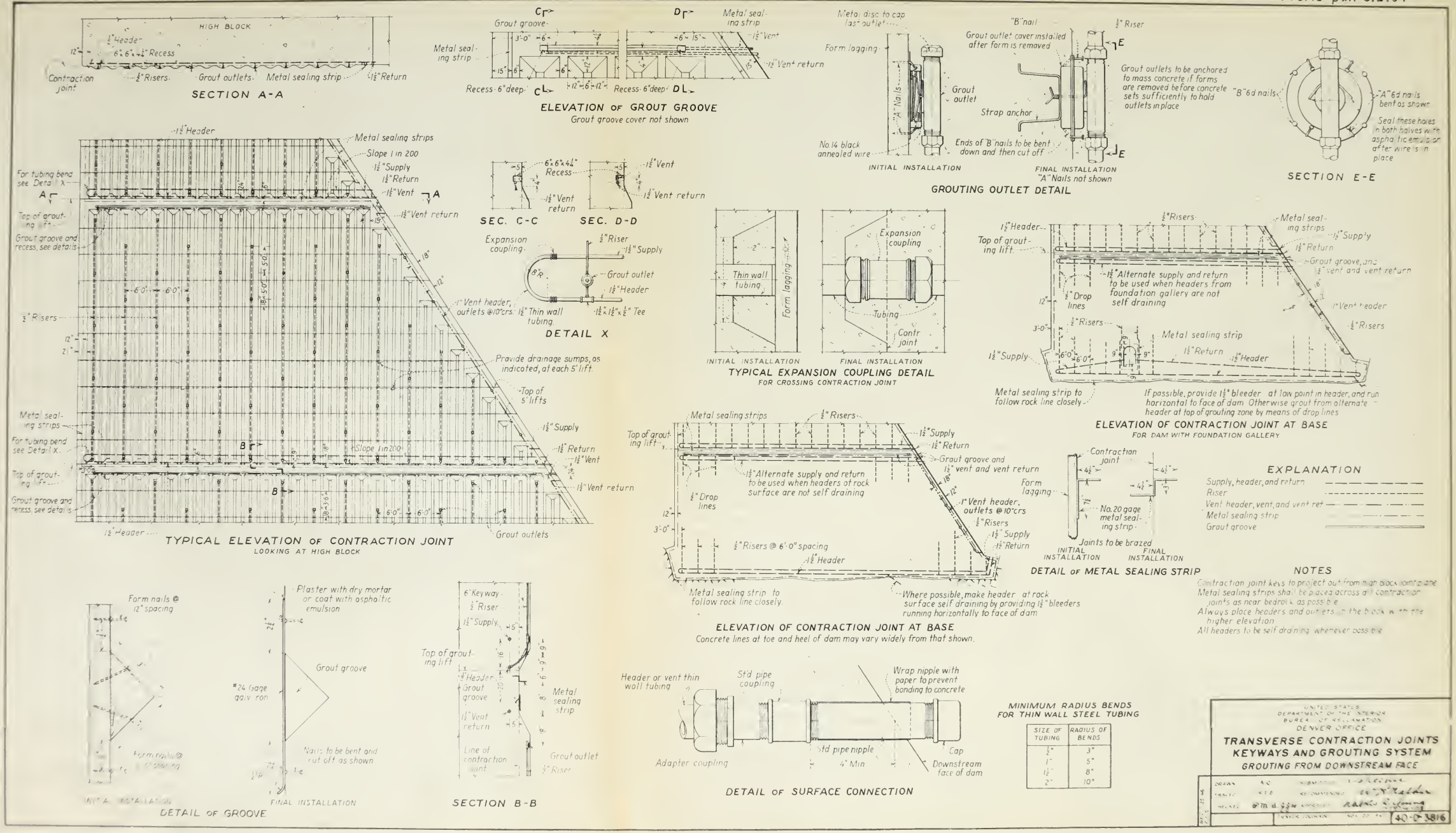
TRANSVERSE CONTRACTION JOINTS KEYWAYS AND GROUTING SYSTEM

GROUTING FROM GALLERIES

DRAWN A.P. SUBMITTED
TRACED R.E.D. RECOMMENDED
CHECKED APPROVED
DENVER, COLORADO 40-D-355

FIG. 15 par. 5.2.64




HIGH BLOCK
½" Header
6"x6"x4½" Recess
Contraction joint
½" Risers
Grout outlets
Metal sealing strip
1½" Return
SECTION A-A
Grout groove
Metal sealing strip
Recess-6" deep
1½" Vent
1½" Vent return
ELEVATION OF GROUT GROOVE
Grout groove cover not shown
Metal disc to cap last outlet
Form lagging
Grout outlet
Strap anchor
No. 14 black annealed wire
Ends of "B" nails to be bent down and then cut off
INITIAL INSTALLATION
"B" nail
Grout outlet cover installed after form is removed
½" Riser
Grout outlets to be anchored to mass concrete if forms are removed before concrete sets sufficiently to hold outlets in place
FINAL INSTALLATION
"A" Nails not shown
GROUTING OUTLET DETAIL
"B" 6d nails
"A" 6d nails bent as shown
Seal these holes in both halves with asphaltic emulsion after wire is in place
SECTION E-E
1½" Header
Metal sealing strips
Slope 1 in 200
1½" Supply
1½" Return
1½" Vent
1½" Vent return
For tubing bend see Detail X
Top of grouting lift
Grout groove and recess, see details
½" Risers
Provide drainage sumps, as indicated, at each 5' lift
Top of 5' lifts
1" Vent header, outlets @10" crs.
½" Thin wall tubing
Grout outlets
TYPICAL ELEVATION OF CONTRACTION JOINT
LOOKING AT HIGH BLOCK
SEC. C-C
SEC. D-D
Expansion coupling
½" Riser
Grout outlet
1½" Header
1½"x½"x½" Tee
DETAIL X
Thin wall tubing
Form lagging
Tubing
Contr joint
INITIAL INSTALLATION
FINAL INSTALLATION
TYPICAL EXPANSION COUPLING DETAIL
FOR CROSSING CONTRACTION JOINT
½" Risers
Metal sealing strips
1½" Alternate supply and return to be used when headers from foundation gallery are not self draining
½" Drop lines
1" Vent header
Metal sealing strip
1½" Return
1½" Header
Metal sealing strip to follow rock line closely
If possible, provide 1½" bleeder at low point in header, and run horizontal to face of dam. Otherwise grout from alternate header at top of grouting zone by means of drop lines
ELEVATION OF CONTRACTION JOINT AT BASE
FOR DAM WITH FOUNDATION GALLERY
1½" Alternate supply and return to be used when headers of rock surface are not self draining
Grout groove and ½" vent and vent return
½" Risers @ 6'-0" spacing
Where possible, make header at rock surface self draining by providing 1½" bleeders running horizontally to face of dam
ELEVATION OF CONTRACTION JOINT AT BASE
Concrete lines at toe and heel of dam may vary widely from that shown.
Contraction joint
Form lagging
No. 20 gage metal sealing strip
Joints to be brazed
DETAIL OF METAL SEALING STRIP
EXPLANATION
Supply, header, and return
Riser
Vent header, vent, and vent ret
Metal sealing strip
Grout groove
NOTES
Contraction joint keys to project out from high block joints one
Metal sealing strips shall be placed across all contraction joints as near bedrock as possible
Always place headers and outlets in the block with the higher elevation
All headers to be self draining whenever possible
Form nails @ 12" spacing
Plaster with dry mortar or coat with asphaltic emulsion
Grout groove
#24 gage galv. iron
Nails to be bent and cut off as shown
FINAL INSTALLATION
DETAIL OF GROOVE
6" Keyway
½" Riser
1½" Supply
Top of grouting lift
½" Header
Grout groove
1½" Vent return
Line of contraction joint
Metal sealing strip
Grout outlet
½" Riser
SECTION B-B
Header or vent thin wall tubing
Std pipe coupling
Wrap nipple with paper to prevent bonding to concrete
Adapter coupling
Std pipe nipple
4" Min
Cap
Downstream face of dam
DETAIL OF SURFACE CONNECTION
MINIMUM RADIUS BENDS FOR THIN WALL STEEL TUBING
SIZE OF TUBING | RADIUS OF BENDS
½" | 3"
1" | 5"
1½" | 8"
2" | 10"
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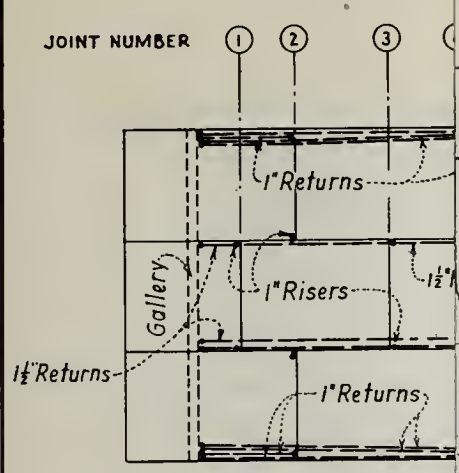
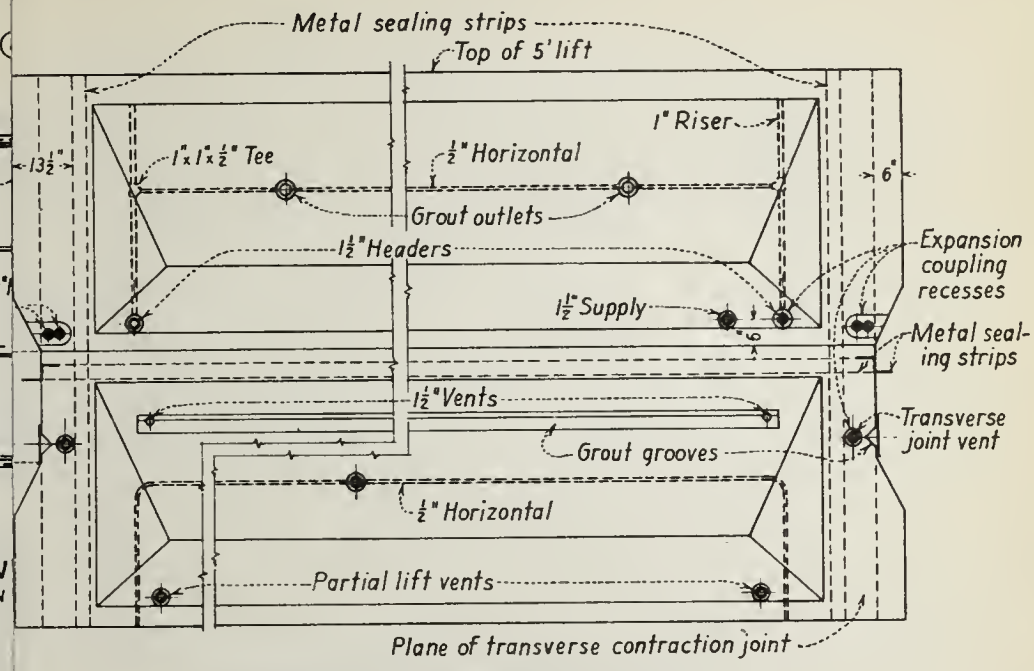
DENVER OFFICE
TRANSVERSE CONTRACTION JOINTS
KEYWAYS AND GROUTING SYSTEM
GROUTING FROM DOWNSTREAM FACE
40-D-3816

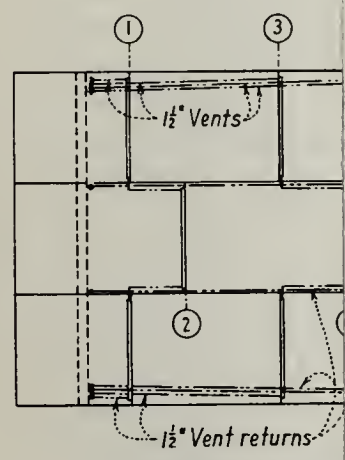
FIG. 16 par. 5.2.65



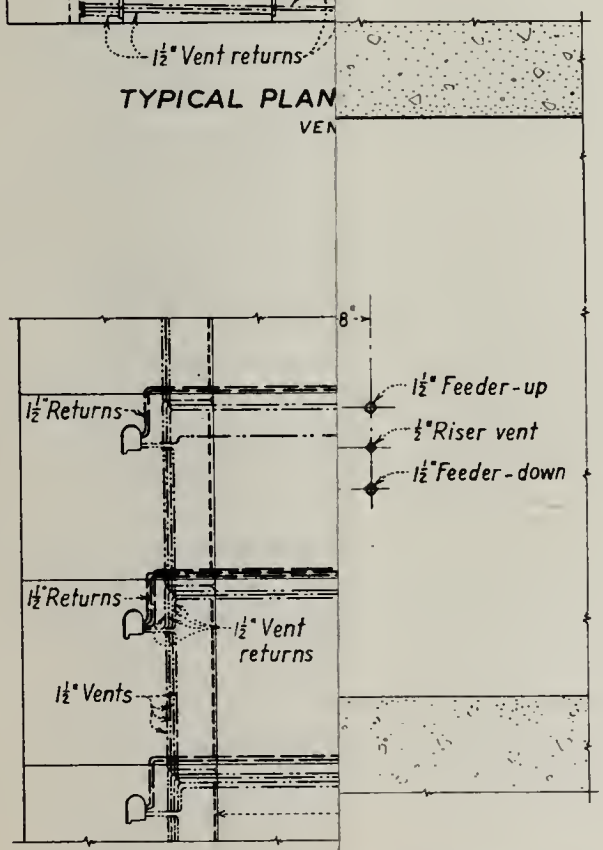
TYPICAL PLAN
SUPPLY, RETURN



ELEVATION OF LONGITUDINAL JOINT
UPSTREAM FACE OF HIGH BLOCK



TYPICAL PLAN
VEN



Note: Provide 1½" bleeder at lo
system at foundation
able gallery or shaft.

GROUT LINES ON
FACE OF GALLERY

REFERENCE DRAWING

TRANSVERSE CONTRACTION JOINTS-KEYWAYS AND GROUTING SYSTEM - SHEET 1 of 2 .....40-D-3813.

NOTE

For notes, explanation, and detail of surface connections, see sheet No. 1

A solid circle indicates a pipe that bends away from the section. An open circle indicates a pipe that is cut by the section.

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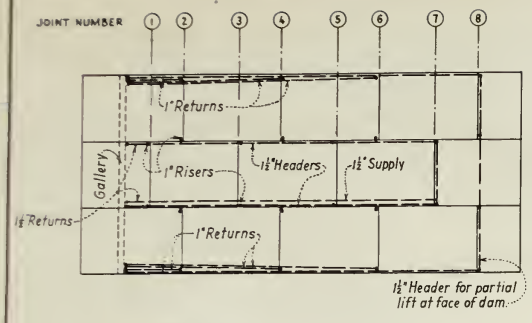
LONGITUDINAL CONTRACTION JOINTS

KEYWAYS AND GROUTING SYSTEM

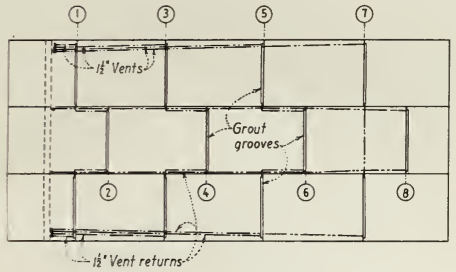
DRAWN A.O. SUBMITTED Nelson B. Bennett
TRACED R.E.B. RECOMMENDED W. H. Nalder
CHECKED O.M. J.J.H. APPROVED Walker R. Young CHIEF ENGINEER

DENVER, COLORADO. NOV. 20, 1945 SHEET 2 OF 2

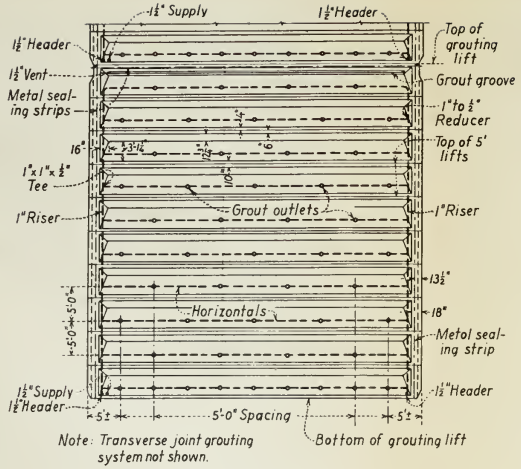
40-D-3814



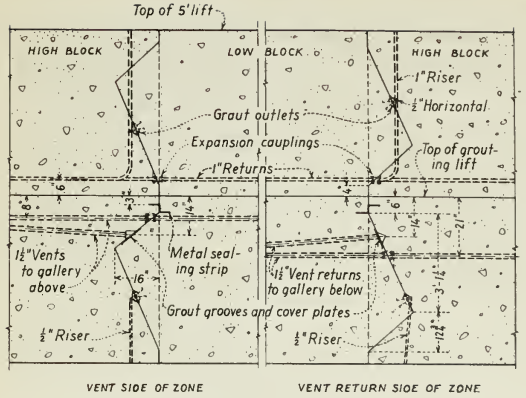
TYPICAL PLAN OF GROUTING ZONE
SUPPLY, RETURN AND HEADER LAYOUT



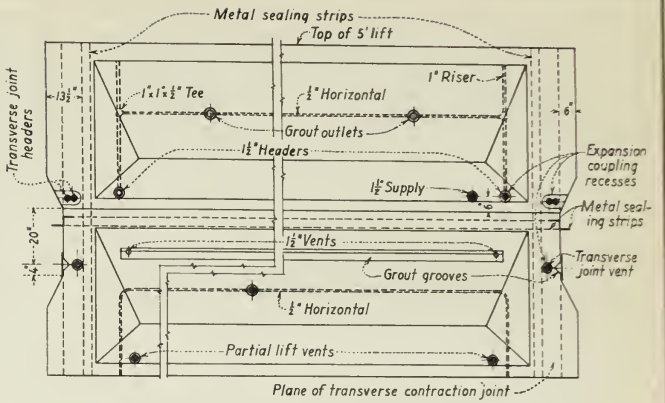
TYPICAL PLAN OF GROUTING ZONE
VENT SYSTEM



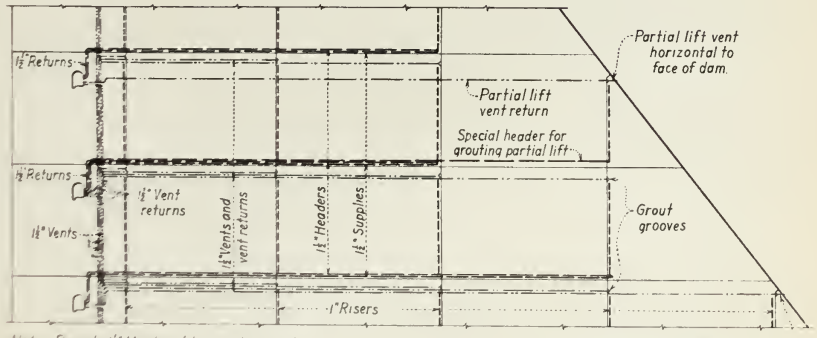
ELEVATION
DOWNSTREAM FACE OF HIGH BLOCK



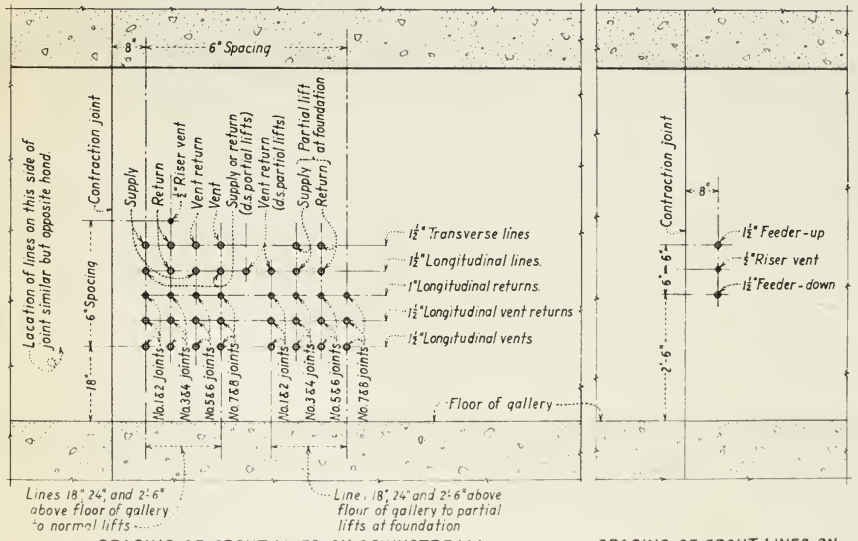
SECTION THRU LONGITUDINAL JOINTS



ELEVATION OF LONGITUDINAL JOINT
UPSTREAM FACE OF HIGH BLOCK



TYPICAL SECTION
½" Horizontals not shown



SPACING OF GROUT LINES ON DOWNSTREAM FACE OF GALLERY

SPACING OF GROUT LINES ON UPSTREAM FACE OF GALLERY

Note: Only part of lines shown will be required on one side of joint in any instance, but location of any particular line relative to contraction joint and floor of gallery shall be as shown.

REFERENCE DRAWING
TRANSVERSE CONTRACTION JOINTS-KEYWAYS AND GROUTING SYSTEM - SHEET 1 of 2 — 40-D-3813

NOTE
For notes, explanation, and detail of surface connections, see sheet No. 1
A solid circle indicates a pipe that bends away from the section. An open circle indicates a pipe that is cut by the section.

UNITED STATES
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BUREAU OF RECLAMATION
DENVER OFFICE

LONGITUDINAL CONTRACTION JOINTS
KEYWAYS AND GROUTING SYSTEM

DRAWN A.O. SUBMITTED
TRACED S.E.B. RECOMMENDED
CHECKED APPROVED

DENVER, COLORADO NOV. 24, 1943
SHEET 2 of 2

40-D-3814

(.66)
downstream face and grouting is performed from catwalks. In order that header ends will not be exposed after grouting operations have been completed, the headers are terminated with a protruding pipe nipple which is wrapped with paper to prevent bonding with the concrete. This nipple is removed when no longer needed and the hole thus formed dry-packed with mortar. Details of the various pipe fittings and piping arrangements to galleries or to the downstream face are illustrated in Figures 14, 15, and 16.

GROUT OUTLETS

.67 Grout outlet units, details of which are illustrated in the figures previously referred to, are assembled from two standard electrical conduit box covers. The covers are embedded in the concrete one on each side of the joint, with open faces together and flanges in contact. The cover in the high block is connected to a tee on the vertical riser and the other cover is blank and is anchored to the low block with metal straps. In erection, the cover which is connected to the pipe system is fastened to the inside of the joint forms with six-penny nails. After the concrete has been placed and the forms removed, the opposite cover of the pair is placed in position and the two are fastened firmly together with wire and by bending down the nails. The concrete in the adjacent block is then placed. As the hardened concrete in the two blocks contracts upon cooling, the box covers are pulled apart and an opening at the flange, equal to the joint opening, is provided for grout injection.

GROUTING OPERATION

.68 The material used in grouting contraction joints is a mixture of cement and water, the consistency of which varies from thin to thick as the operation proceeds. Usually, a two-to-one mixture by volume of water and cement is used at the start of the grouting operation, a one-to-one mixture to fill the system and joint, and, if the joint is wide and accepts grout readily, grout of 0.7 or 0.8 water-cement ratio by volume may be used to finish the operation. Normally, the supply line from the grout pump is connected to the supply header so that grout first enters the joint through outlets in the most remote distribution pipe, thereby setting up conditions most favorable for the expulsion of air, water, and diluted grout as the grouting operations proceed. If the grout introduced in the normal way makes a ready appearance at the return header, the indications are that the header system is unobstructed. Grout from the header is forced up the risers and into the joint through the grout outlets, while air and water is forced up to the vent groove above. When thick grout flows from the vent outlets, injection

(.68)

GROUTING OPERATION (CONT.)

is stopped for a while to allow the grout to settle. After several repetitions of showing of thick grout, the outlet headers are capped. The pressure on the supply line is then increased to the allowable limit for the particular joint so as to force grout into all small openings of the joint and to force the excess water into the pores of the concrete, leaving a grout film of lower water-cement ratio and higher density. This limiting pressure, usually not over 50 pounds per square inch, must be low enough to avoid deflecting the block excessively or causing a V-shaped opening of the grouted portion of the joint below. This maximum pressure is maintained until no more grout can be forced into the joint, and the system is sealed off.

SPILLWAYS

.69 The purpose of a spillway is to provide a means for the passage of flood flows without damage to the dam or its appurtenant structures. Any one of several types may be constructed depending upon topographical and geological conditions at the site, type of dam, discharge capacity required, and relative costs. The following discussion deals particularly with the overfall or ogee type of spillway constructed as an integral part of a gravity dam. General descriptions of other types and factors affecting their use and design are discussed in Chapter 5.6.

DESIGN CONSIDERATIONS

.70 Basic considerations affecting the design of the spillway include: capacity required, degree of crest control desired, conditions affecting crest length, and structural stability.

CAPACITY

A. The capacity of the spillway must be sufficient to accommodate the maximum discharge without allowing the reservoir surface to rise above a predetermined maximum elevation in order to prevent flood damage to property bordering on the reservoir. The relation between the design capacity of the spillway and the maximum rate of inflow to the reservoir during flood flow will depend on the operating characteristics of the reservoir. As the normal operating elevation of the reservoir approaches the maximum allowable elevation for flood stage, the flood storage capacity of the reservoir is reduced and the discharge capacity of the spillway approaches the maximum rate of inflow. The determination of the maximum flood to be used as a basis for spillway design results from hydrological studies of available flood hydrographs as discussed in Chapter 2.5 of the Project Planning Handbook. Methods of determining spillway capacity compatible with the maximum design flood, considering reservoir storage

(.70A)

effect (flood routing), are discussed in Chapter 5.6 of this Handbook.

B. A spillway crest may be uncontrolled, thereby permitting water to spill from the reservoir whenever the water surface is at a higher elevation than the crest; or gates may be installed on the crest, thereby providing a means for controlling the discharge as the reservoir rises above the elevation of the crest. An uncontrolled spillway automatically provides for some flood control, since part of the flood is temporarily stored while the discharge head above the crest is built up. The required capacity of an uncontrolled spillway may therefore be less than the maximum rate of inflow to the reservoir. A completely controlled crest is one which maintains the reservoir elevation at or close to the maximum. Such a crest must therefore be designed to accommodate the maximum rate of inflow to the reservoir. Assuming the maximum elevation of the reservoir surface at the dam to be fixed, the effect of reducing crest control by decreasing the height of the gates would be to increase the flood storage capacity of the reservoir, decrease the required discharge capacity of the spillway, and reduce the normal operating elevation of the reservoir which in turn reduces the amount of water storage for irrigation purposes and reduces the head available at the power plant. Economic studies may be made involving the effect of the above variables on the annual net costs and net returns on the total investment in order to select the degree of control that should be installed. CREST CONTROL

C. The length of the spillway crest affects the elevation of the crest and also the height of gates required if the crest is controlled. If the length is restricted by topographical conditions at the site or by the powerplant, the crest must be lowered in order to provide the required capacity, and the height of gates increased in order to maintain the desired normal operating elevation of the reservoir. If no outside influence restricts the length of the spillway, the relation between length and crest elevation may be determined from a cost study of various gate types and sizes. CREST LENGTH

D. In order that the spillway section of a gravity dam will be stable under all conditions of discharge, its design is governed by the same criteria and is STRUCTURAL STABILITY

(.70D)

subjected to the same structural analysis as discussed later in this Chapter for the non-overflow section of the dam.

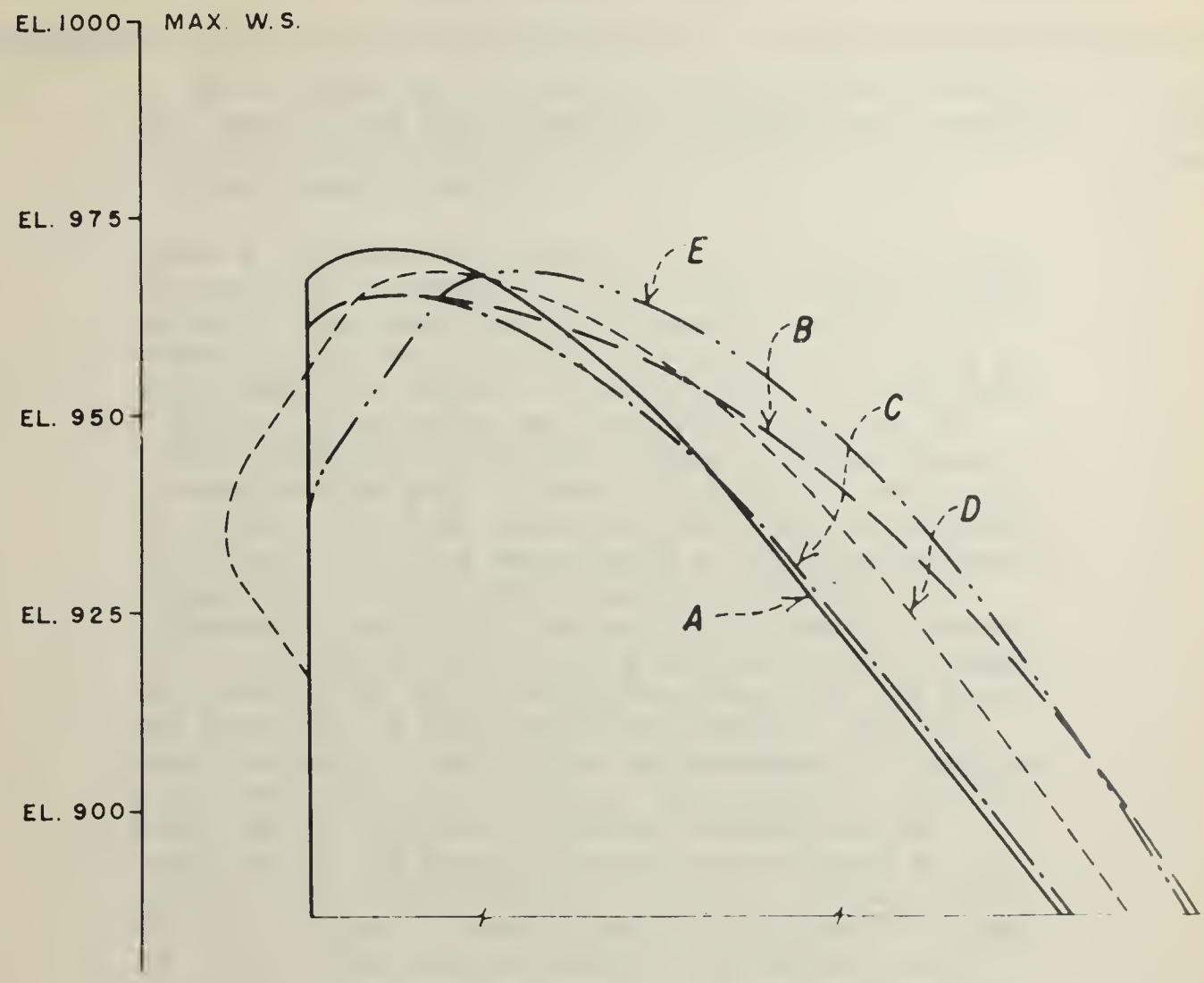
CREST SHAPES

.71 Usually, the spillway crest is so shaped that, for all conditions of discharge, the pressure between the lower nappe of the overflowing sheet of water and the face of the spillway is not less than atmospheric. For uncontrolled crests, the critical condition occurs at maximum discharge and the crest is shaped to conform to the lower nappe of a jet of water discharging over a sharp crested weir under equivalent conditions of head and slope of upstream face. When the crest is controlled by gates of the lift type, two conditions of flow govern the shape. The portion of the crest upstream from the gate is designed to fit the weir nappe at maximum discharge while the portion of the crest downstream from the gate is shaped to fit the theoretical trajectory of the centerline of the jet issuing from a 1-foot gate-opening under maximum head. The result is a crest which is flatter than one designed for maximum discharge alone. The size and shape of drum gates require a fairly broad crest for their accommodation. Therefore when using drum gates, the shape of the crest is based on a design head greater than the height of the gate and the theoretical crest obtained by using this higher head is then adjusted to fit circular curves for the portion of the crest covered by the gate in order to simplify gate layout and fabrication. The required design head is obtained by a method of trial, the particular gate to be used being fitted to each trial crest until a crest is obtained which will accommodate the structural features of the gate. The computations necessary to determine the crest coordinates for the varying conditions listed above are discussed in Hydraulic Report No. 118 which is an abstract of "Studies of Crests for Overfall Dams." Bulletin 3, Part VI - Hydraulic Investigations - Boulder Canyon Final Reports.

EFFECT OF GATES

A. Figure 17 shows the effect of gates on the shape of a spillway crest. The several solid and broken lines define the crest shapes required for various types of crest control. Computations were based on the following uniform assumptions: maximum water surface elevation of the reservoir constant; total length of spillway, including piers, constant; elevation of approach channel constant; and maximum discharge at maximum reservoir elevation constant. Since the total length of spillway, including piers, was held constant, the unrestricted length of crest and elevation

FIG. 17 . par. 5.2. 71



DESIGN CRITERIA

Crest **A** - Uncontrolled
Crest **B** - Vertical Lift Gates, 1 ft. gate opening
Crest **C** - Vertical Lift Gates, max discharge
Crest **D** - Drum Gates - Upstream overhang
Crest **E** - Drum Gates - No overhana

Constants:
Max. reservoir elevation 1000
Length of spillway including piers 400 ft.
Max. discharge 250,000 s.f.

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EFFECT OF GATES ON SHAPE OF SPILLWAY CREST

BY GRR	APRIL 25, 1946
APR CR.	MD-DT-2

(.71A)

of crest varied in accordance with the type of gate. The value of the coefficient of discharge was corrected in each case to conform to the conditions existing for each type of control.

CREST SHAPES (CONT.)

B. Curve A illustrates the shape of crest obtained when the crest is uncontrolled. This crest has the highest value for the coefficient of discharge and from a hydraulic standpoint is the most efficient. Curve B illustrates the shape of crest obtained by installing lift-type gates and using the design criterion of 1-foot gate-opening for determining the shape downstream from the gate. Curve C illustrates the shape of crest obtained by using the same crest control as for curve B, but the shape based on maximum discharge throughout. A substantial saving in concrete is indicated by using this shape in preference to shape B, but at partial gate opening subatmospheric pressures will develop on the portion downstream from the gate. The magnitude of these negative pressures and the area over which they act can be determined for various gate openings by model tests. The length of time the gates may be operated at partial opening and the magnitude of the negative pressures developed as indicated by model tests may serve as a basis for the choice of shape. Curves D and E illustrate the shape of crest required to accommodate drum gates. By allowing an upstream overhang or lip as indicated by curve D, a saving in concrete can be effected. However, greater difficulty will be experienced in the operation of bulkhead gates should river outlets be located through the spillway section.

.72 A general description of the mechanical features and operating characteristics of the various types of gates used for the control of spillway crests is given in Chapter 6.3. The following discussion presents the more important factors which may govern in the choice of type suitable for a straight ogee-type spillway.

CONTROL GATES

A. The most suitable gate is one which satisfies for the least cost the conditions imposed by the head on the crest, the height of dam, and the hydraulic behavior of the gate.

CONDITIONS AFFECTING CHOICE

(1) In general, the volume of concrete in the crest of the spillway and the cost of the gates and their operating mechanisms increase as the discharge head increases. This indicates that the

DISCHARGE HEAD

(.72A-1)

spillway should be as long as possible in order to effect a reduction in head. Where the total length of spillway is restricted by outside influences, the crest must of necessity be lowered, which argues for the installation of long gates in order to reduce the number of piers.

HEIGHT OF DAM

(2) The height of dam may at times influence the selection of type of gates. In order to use drum gates, the dam must be high enough to accommodate the drum gate chamber with sufficient concrete section below the chamber to satisfy requirements for structural stability.

HYDRAULIC BEHAVIOR

(3) Hydraulic behavior at various gate openings may influence selection of type since some gates are more sensitive than others to the drawdown effect of the issuing jet at partial opening. Also, the interference to flow and cavitational tendencies created at the higher heads by the guide grooves required for vertical-lift gates may favor the selection of another type.

TYPES OF GATES

B. The most common types of gates used by the Bureau are: radial gates, vertical-lift leaf gates, drum gates, and roller gates.

RADIAL GATES

(1) Radial gates are relatively simple in design and are constructed entirely of structural steel shapes requiring no precision machining except for the pin assembly. The cost per pound of assembled gate is therefore, relatively low. The entire water load is concentrated at the pins and the only lifting force necessary is that to overcome the weight of the gate itself and a small amount of friction at the pins. Radial gates have been installed in sizes up to 51-feet long by 31-1/2-feet high. The present trend indicates the use of this type of gate for even higher heads. Contemplated designs for the Bhakra Dam in India call for radial gates 50-feet long by 70-feet high.

VERTICAL-LIFT LEAF GATES

(2) Vertical-lift leaf gates require guide grooves in their supporting piers which may produce unsatisfactory hydraulic conditions under high heads unless preventive measures are taken. In order to reduce the friction between the gate and the guide, these gates are usually equipped with a series of fixed wheels or roller assemblies,

(.72B-2)

which require the use of special metals and precise machining of the component parts. Gates of this type have been used by the Bureau in sizes up to 50-feet long by 50-feet high.

(3) The drum gate, developed by the Bureau of Reclamation, offers a relatively long unobstructed crest and is operated entirely by hydraulic pressure. This feature introduces an additional safety factor in that its operation is assured in the event of failure of the station power system. Gates of this type have been installed in sizes up to 135-feet long by 28-feet high. Contemplated designs for similar gates for the Yangtze River Project in China call for sizes 135-feet long by 56-feet high. DRUM GATES

(4) The roller gate also offers a relatively long unobstructed crest and has been used by the Bureau for relatively low dams where this feature is desirable. The largest gate of this type designed by the Bureau is 110-feet long by 17-1/4-feet high. The height of piers required for this type of gate would preclude its use on high dams, where the cost of a drum gate installation would be more economical. ROLLER GATES

.73 Piers may be located on the crest of the spillway for the purpose of supporting the control gates, housing the gate operating mechanisms, or for supporting a highway or gate operating bridge. The size and shape will vary in accordance with its function. In order to reduce contraction of the overflowing jet and provide a smoother water passage, the upstream ends of the piers are usually rounded or pointed. PIERS

.74 In cold climates, gate operation may be hampered by freezing of the seals to piers or by the formation of ice on the piers or gate guides, which may cause the gate to bind when operated. In order to avoid such conditions and insure continuous operation of gates, appurtenances for dams designed for northern latitudes will include provision for ice control depending on the temperatures expected. In order to keep the end seals free, heat may be applied to the surface of the pier plate or guide groove by steam pipes or electric coils embedded in the concrete behind the seal contact area. Satisfactory conditions may also be obtained by admitting compressed air to the water at the base of gate guides, thereby causing a continuous upward movement of the relatively warmer water existing below the surface. The formation of ice on the gate itself may be prevented by the installation of heaters behind the skin plates. ICE CONTROL

ENERGY DISSIPATION

.75 One of the most important considerations in the design of a spillway section is the method of controlling erosion of the river bed at the downstream toe. An enormous amount of energy, which can be measured in millions of horsepower for some spillways, must be dissipated before the flow comes in contact with the natural stream bed. Factors which affect the choice of method of dissipating this energy and the design of the resulting energy-dissipating structure include conditions of discharge, height of fall, depth of tailwater, and the nature of the stream bed material. The effect of minor change in any one of the above factors may be sufficient to cause the abandonment of a proposed scheme for energy dissipation and require the adoption of another. Each project presents its own problems which can be solved only after a careful study of existing conditions and hydraulic laboratory tests on models.

METHODS

.76 Of the several methods proposed for the control of erosion, the most common employ one or a combination of the following principles or devices: the hydraulic jump, use of devices for stabilizing the jump body, the diffusion principle, or the trajectory. Each method of erosion control seeks to decrease the high velocity of the plunging jet by the creation of violent turbulence within the bucket or curved toe of the spillway, as the flow leaves the bucket, or before the flow leaves the apron or paved downstream extension of the bucket. Economic considerations require that the velocity conditions be made compatible with tailwater depth within a limited distance from the dam.

HYDRAULIC JUMP

A. The hydraulic jump is one of the most effective means of absorbing the kinetic energy of high velocity flows. It is, however, very sensitive to fluctuating tailwater elevation and may require the construction of various devices to aid in maintaining proper conditions for its formation. For a given depth and velocity of the plunging jet, a particular depth of tailwater is necessary for the formation of the hydraulic jump. Under constant discharge, as the tailwater depth increases beyond that necessary for the jump to form, the head of the jump will move upstream and ascend the face of the spillway until it becomes completely submerged. Under these conditions, the accompanying turbulence becomes less violent and a tendency is developed for the high velocities of the plunging jet to persist further downstream. In actual practice, the tailwater depth increases as the discharge increases and the head of the jump moves downstream, necessitating a longer energy dissipating structure. As the tailwater

(.76A)

depth becomes less than that required to produce the jump, the head of the jump will move downstream to a location where the velocity of the jet has been reduced by channel friction and its depth correspondingly increased to values consistent with tailwater depth at that location for the formation of the jump. Under these conditions, if the jump has moved downstream so as to occur beyond the limits of the apron, the riverbed will be exposed to the destructive action of the full velocity of the jet. The design of the energy dissipating structure, therefore, must be such that the jump will occur within the limits of the structure under all conditions of discharge.

HYDRAULIC JUMP (CONT.)

B. Various devices for stabilizing the hydraulic jump body have been developed, the effectiveness of each depending upon velocity and depth of the plunging jet and the accompanying tailwater conditions.

JUMP STABILIZATION

(1) Experience has shown that baffle piers, continuous baffles, or variously shaped obstructions or teeth (dentates) in the path of the high velocity jet tend to maintain conditions favorable to the localization of the jump as tailwater fluctuates, thereby reducing the length of apron required. The design of size and shape of these obstructions can be determined only from model test indications, since slight changes of shape or proportion may produce submerged flow conditions which may undercut the apron. At high dams, the velocity of the jet may be such as to produce destructive cavitational effects on the dentates which would prohibit their use. A preliminary design of the spillway for Angostura Dam illustrating the use of dentates is given in Figure 18.

BAFFLES, PIERS, DENTATES

(2) When the tailwater depth is less than that required for the jump, additional depth may be provided by excavating the stream bed and lowering the apron until the desired depth is obtained. The resulting structure is called a stilling basin or stilling pool. A stilling pool may also be created by the construction of a relatively massive continuous baffle or auxiliary dam across the channel downstream from the dam, the height of this baffle being such as to develop the desired tailwater depth. Stilling pools usually vary in length from four to six times the depth of maximum tailwater depending upon the slope of the floor and use of other energy dissipating devices such as dentates or baffle

STILLING POOLS

(.76B-2)

piers. The floor must be of such thickness as to resist uplift pressures equal to the hydrostatic head produced by maximum tailwater. If the foundation is somewhat porous, provision for foundation drainage beneath the apron may be included in the design.

SLOPING APRON

(3) As stated earlier, higher discharges tend to cause the hydraulic jump to occur farther downstream on the apron. Elevating the apron at the downstream face of the spillway and sloping it downstream will tend to make the jump occur in the same general location at various discharges, and the length of apron may thereby be reduced. The amount of concrete saving in reducing the length may be offset, however, by an increase in thickness at the toe. Effective erosion control for varying discharges and tailwater depths may be obtained by combining the sloping apron and the stilling pool as illustrated in Figure 19.

ROLLER BUCKET

(4) For high dams with high flows and deep tailwater, the apron that would be required might be so large as to be too costly. Under these conditions satisfactory results may be produced by setting the bucket deep in the tailwater and extending its curvature so that the issuing jet will be turned upward, forming a high boil above the lip and a large roller in the bucket. Care must be exercised in the design to prevent the formation of a destructive submerged ground roller immediately downstream from the bucket.

DIFFUSION METHOD

C. The diffusion bucket, examples of which are illustrated in Figure 20, has been used satisfactorily for moderately high dams with varying tailwater conditions. The design is characterized by a lip containing notches with sides sloping outward and upward in the direction of flow. Water entering the relatively narrow upstream openings of the notches is forced to diffuse over a much larger area at the top and downstream exit thereby losing much of its velocity.

TRAJECTORY METHOD

D. The trajectory method employs a bucket set above tailwater and so shaped that the discharge is thrown up and clear of the downstream face to strike the tailwater surface at a safe distance from the toe of the dam. This method requires deep tailwater and may be safe so long as the lip of the bucket remains above tailwater, otherwise a large roller will develop at the bucket lip, which may cause undermining of the toe.

FIG. 18 par. 5.2.76

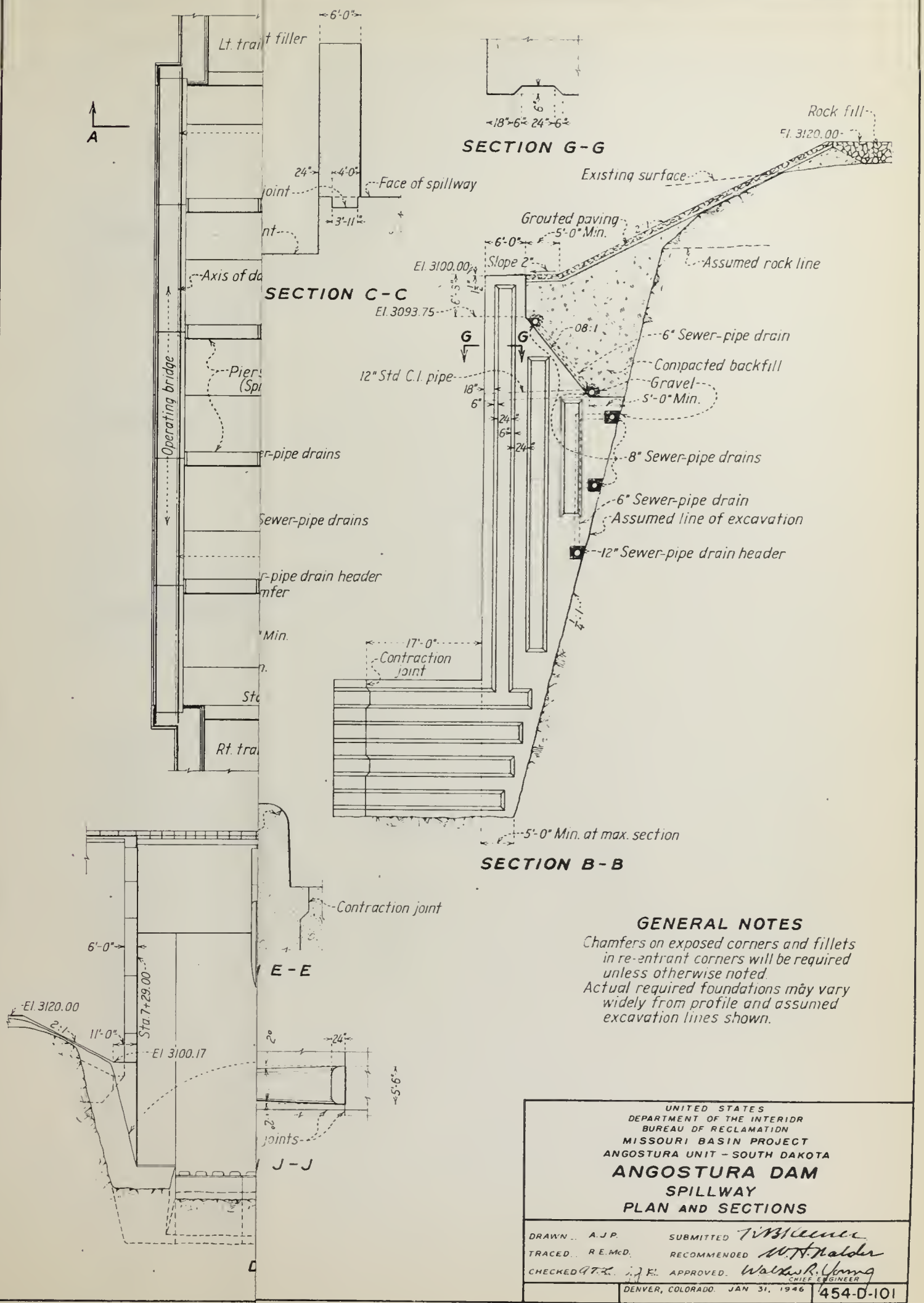


FIG 18 par. 5 2 76

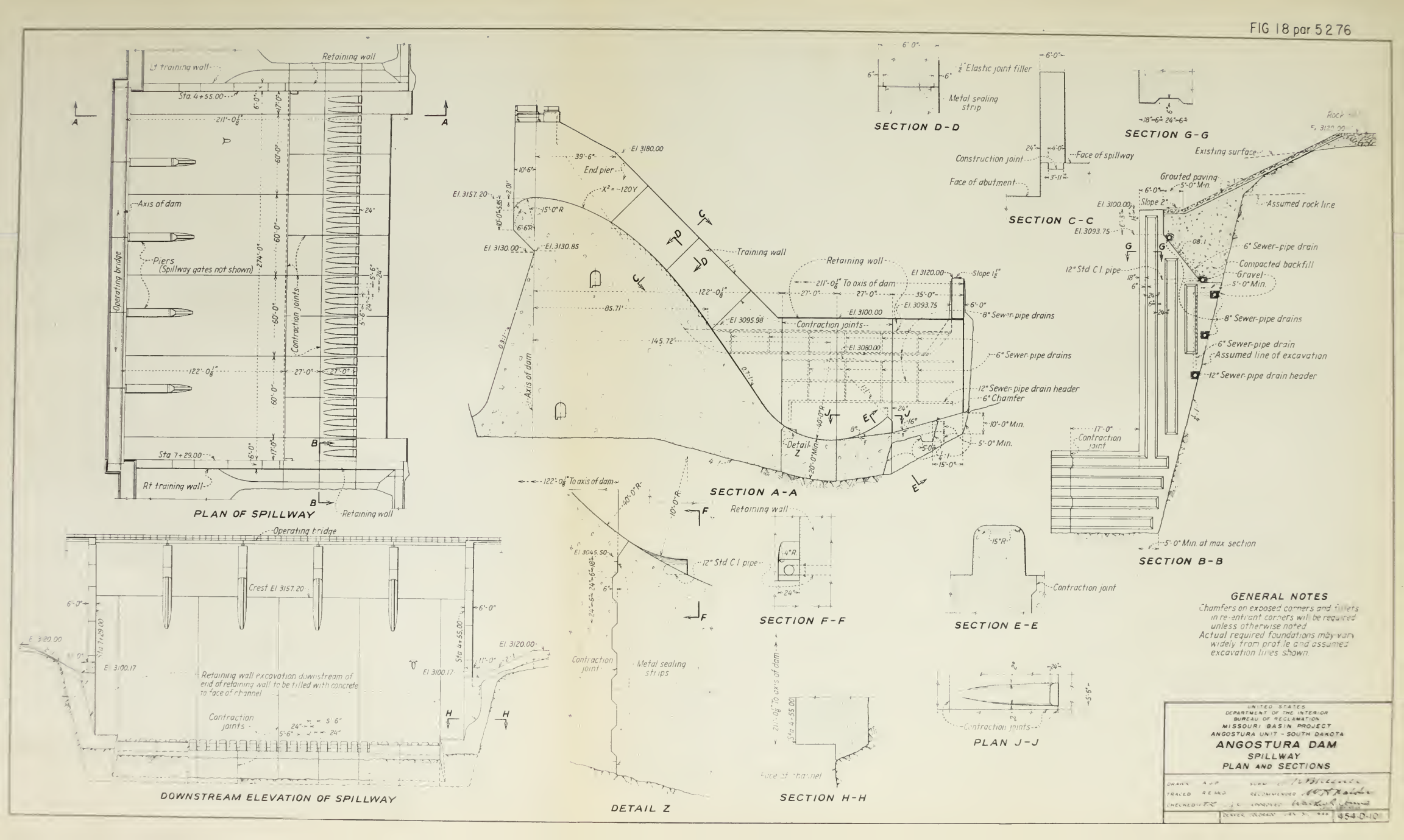
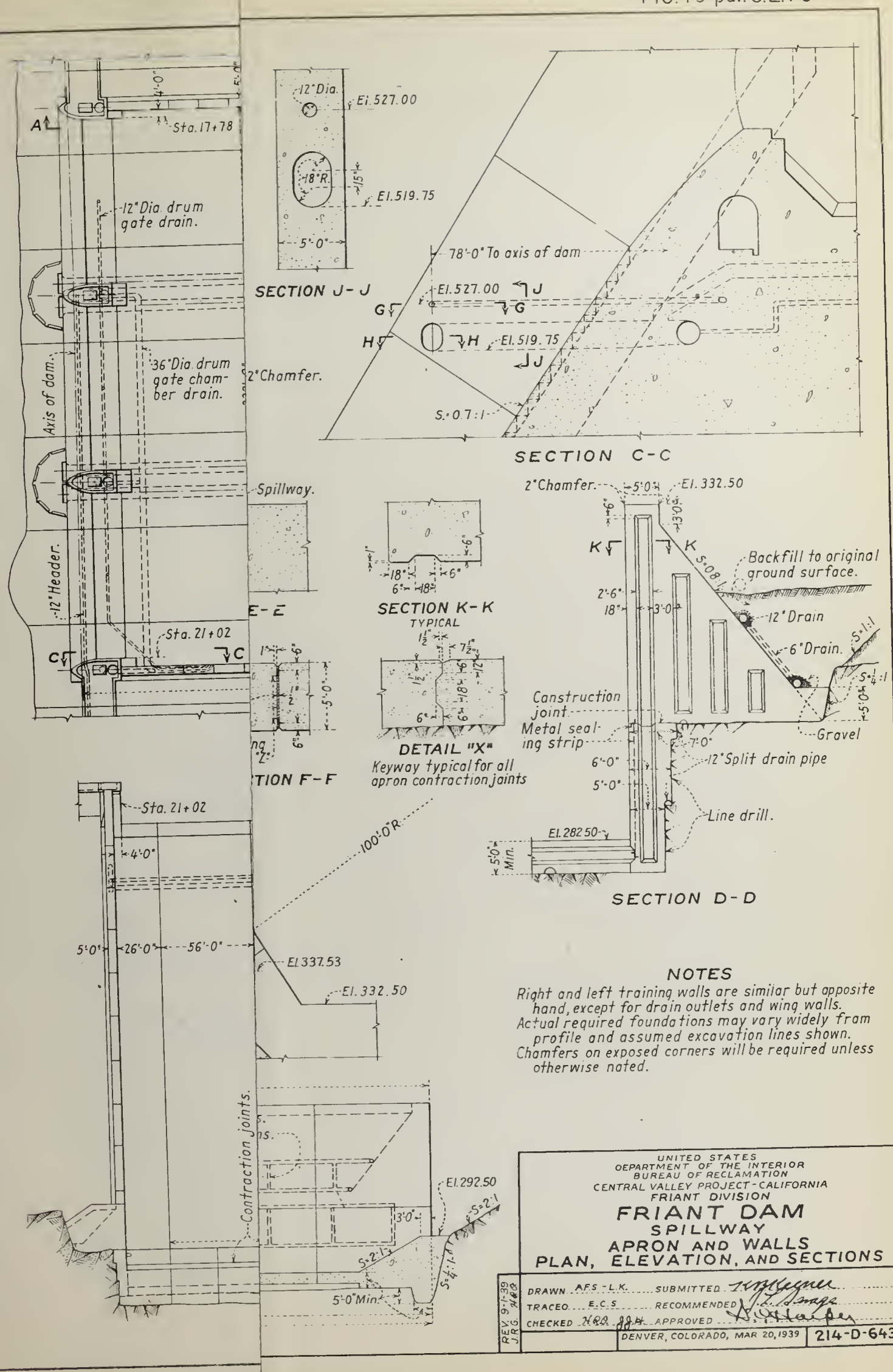
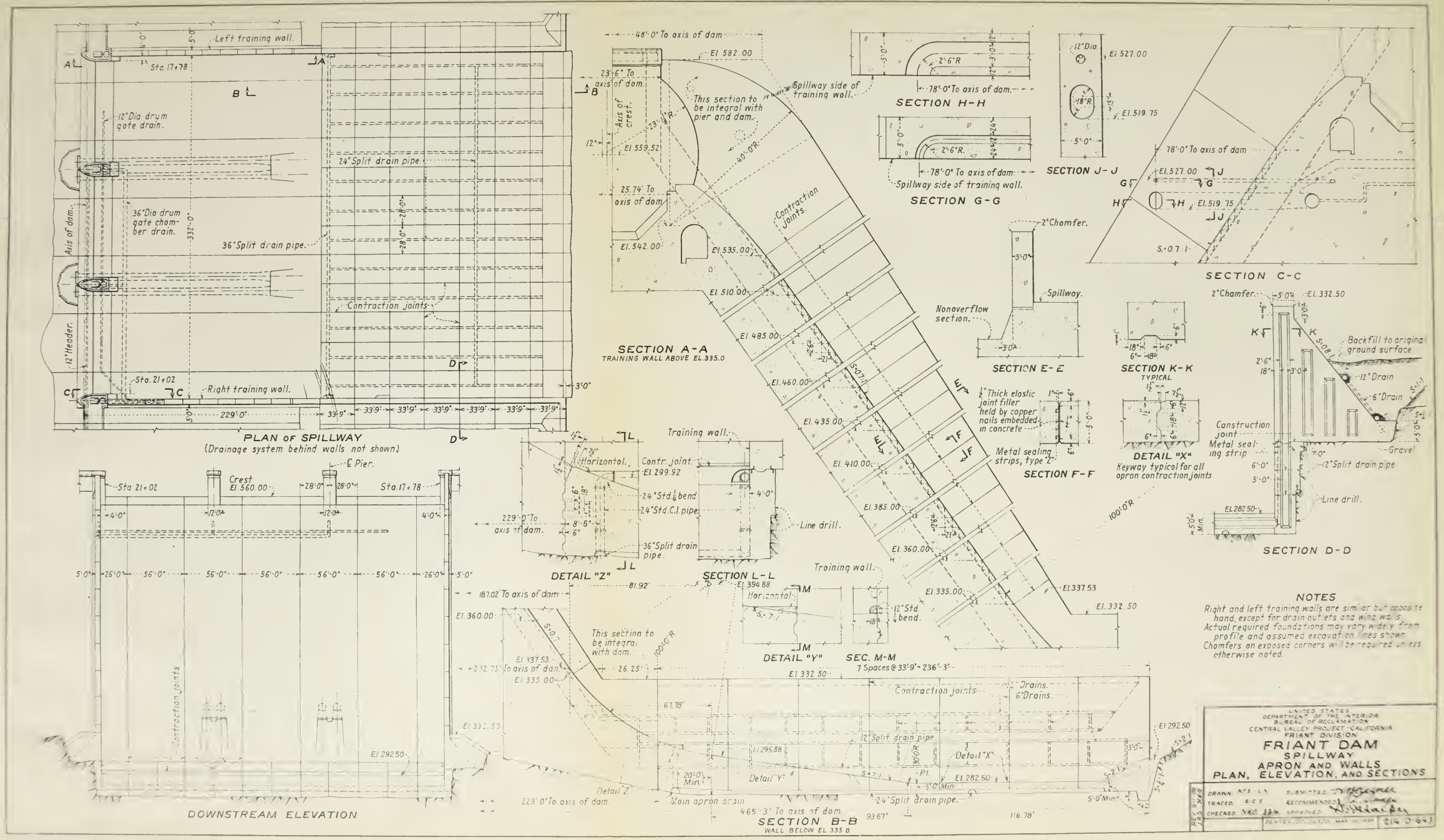
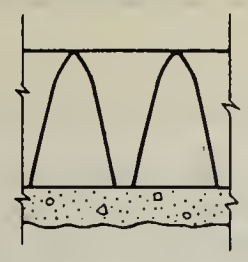


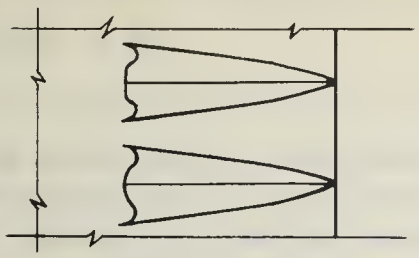
FIG. 19 par. 5.2.76



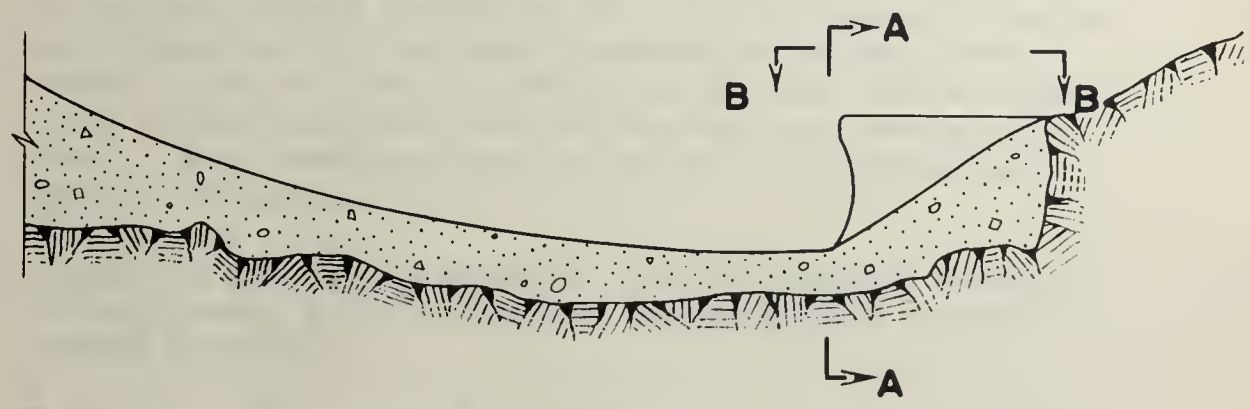

PLAN OF SPILLWAY
(Drainage system behind walls not shown)
Left training wall.
Right training wall.
Sta. 17+78
Sta. 21+02
12" Dia. drum gate drain.
36" Dia. drum gate chamber drain.
24" Split drain pipe.
36" Split drain pipe.
Contraction joints.
Axis of dam.
12" Header.
229'-0"
33'-9"
SECTION A-A
TRAINING WALL ABOVE EL. 335.0
48'-0" To axis of dam
El. 582.00
23'-6" To axis of dam.
Axis of crest.
This section to be integral with pier and dam.
Spillway side of training wall.
El. 559.52
25.74' To axis of dam
El. 542.00
El. 535.00
El. 510.00
El. 485.00
El. 460.00
El. 435.00
El. 410.00
El. 385.00
El. 360.00
El. 335.00
El. 337.53
El. 332.50
SECTION H-H
78'-0" To axis of dam.
SECTION G-G
Spillway side of training wall.
SECTION J-J
12" Dia.
El. 527.00
El. 519.75
SECTION C-C
S. 0.7:1
2" Chamfer.
Spillway.
Nonoverflow section.
SECTION E-E
SECTION K-K
TYPICAL
DETAIL "X"
Keyway typical for all apron contraction joints
½" Thick elastic joint filler held by copper nails embedded in concrete
Metal sealing strips, type Z
SECTION F-F
Backfill to original ground surface
12" Drain
6" Drain
Construction joint
Metal sealing strip
Gravel
12" Split drain pipe
Line drill.
EL 282.50
SECTION D-D
Pier.
Crest El. 560.00
DOWNSTREAM ELEVATION
Contraction joints
Horizontal.
Contr. joint
El. 299.92
24" Std. ¼ bend
24" Std. C.I. pipe
36" Split drain pipe.
Training wall.
Line drill.
DETAIL "Z"
SECTION L-L
El. 394.88
12" Std. ¼ bend.
DETAIL "Y"
SEC. M-M
7 Spaces @ 33'-9" = 236'-3"
187.02' To axis of dam
81.92'
This section to be integral with dam.
100'-0" R
El. 337.53 To axis of dam
El. 335.00
El. 332.50
El. 292.50
Drains.
6" Drains
12" Split drain pipe
El. 295.88
Detail "X"
Detail "Y"
Detail "Z"
Main apron drain
24" Split drain pipe.
229'-0" To axis of dam.
465'-3" To axis of dam.
SECTION B-B
WALL BELOW EL. 335.0
NOTES
Right and left training walls are similar but opposite hand, except for drain outlets and wing walls.
Actual required foundations may vary widely from profile and assumed excavation lines shown.
Chamfers on exposed corners will be required unless otherwise noted.
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT - CALIFORNIA
FRIANT DIVISION
FRIANT DAM
SPILLWAY
APRON AND WALLS
PLAN, ELEVATION, AND SECTIONS
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED



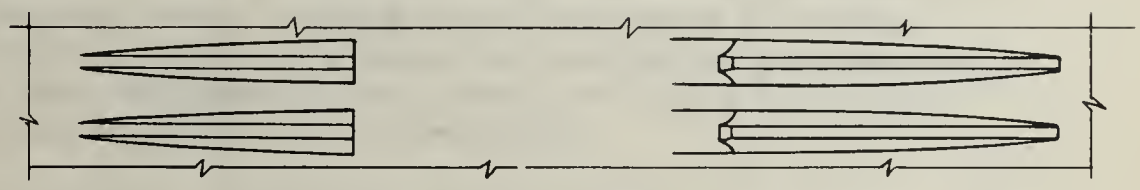
SECTION A-A



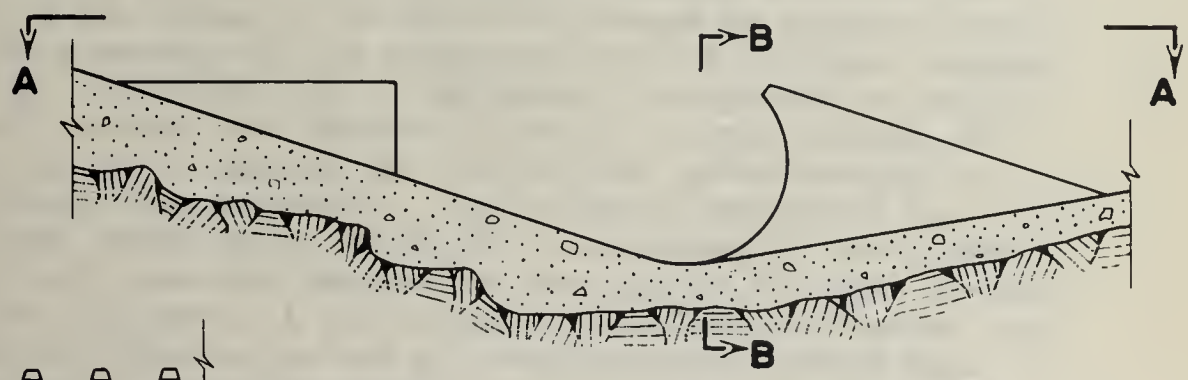
SECTION B-B



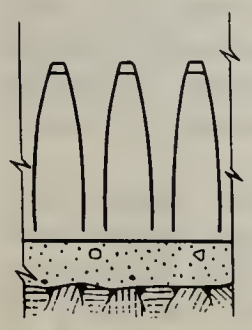
WHEELER DAM



SECTION A-A



ALL-AMERICAN CANAL



SECTION B-B

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

DIFFUSION BUCKET DESIGNS

BY G.R.R.	APRIL 25, 1946
APR. C.R.	MD-DT-5

.77 As indicated in the foregoing discussion, the reduction of the jet velocity to safe channel velocities may be exceedingly difficult. Some discharge conditions may produce velocities along the riverbed which are capable of erosion and can be more economically controlled by lining the channel in the high velocity regions with riprap rather than by extending the apron. Even with perfect performance of the energy-dissipating structure, the channel flow at flood discharge may produce bottom velocities higher than the riverbed material can safely withstand. Such conditions will also call for additional channel protection.

CHANNEL PROTECTION

.78 Figures 18 and 19 are examples of specification drawings for spillways, illustrating the features shown in these general drawings.

SPECIFICATION DRAWINGS FOR SPILLWAYS

.79 The term "outlet works" is applied to the combination of structures and equipment required for the safe operation and control of the water released from the reservoir to serve the various purposes for which the dam was constructed. These structures may be: river outlets, when they serve to regulate the river flow and reservoir elevation; canal outlets, when they serve to provide passage of water to a canal for irrigation purposes below the dam; or power outlets, when they serve to provide passage of water to the powerplant.

OUTLET WORKS

.80 The relative importance and consequently the design of the outlet works will vary in accordance with the size and primary function of the project. Design will also vary with the manner in which the discharge is conducted from the reservoir to the downstream side of the dam. Depending on size and type of structure, topography and geology of the site, and relative costs of various schemes, the water may be passed through the dam, under the dam, or through the abutments. The following paragraphs deal with those outlet works which are incorporated in the design of gravity dams and provide for the passage of water through the structure. A more detailed discussion of design considerations and method of construction of outlet works in general, including details applicable to all types of dams, is given in Chapter 5.6.

DESIGN

.81 The number and size of river outlets must be such that discharge requirements at various elevations of the reservoir will be satisfied. For small discharges, choice of size and number may be relatively easy to determine. As the volume of water to be handled is increased,

RIVER OUTLETS

(.81) however, the effect of other factors becomes more pronounced and should be considered in order that a choice may be made which is both practical and economical.

DESIGN CONSIDERATIONS

.82 Additional design considerations may include: amount of discharge afforded by other means, desirability for close regulation of flow, relative costs of various combinations of size and number, and diversion requirements during construction of the dam.

OTHER DISCHARGES

A. The amount of water discharged through the power outlets may be sufficient to supply a considerable portion of the total requirements downstream. The required capacity of the river outlets may therefore be materially reduced, depending on the operating characteristics of the powerplant.

CLOSE REGULATION

B. When the primary function of the project is to produce power, close regulation of the water surface elevation of the reservoir is desirable in order to maintain as closely as possible a constant head on the turbines. When the primary function of the project is storage of water for irrigation, conservation of water becomes important. Close control of the passage of water through the outlets is therefore a desirable feature for either case. Depending upon the effect of outlet capacity on reservoir capacity and elevation and on the type of control equipment required, more favorable operating conditions may result from the use of a larger number of outlets of smaller size.

RELATIVE COST

C. As the size of outlets increases, the total cost of bulkheads, control gates, and their operating and maintenance equipment also increases. The choice of number and size of river outlets may therefore be based on a detailed cost analysis of various sizes.

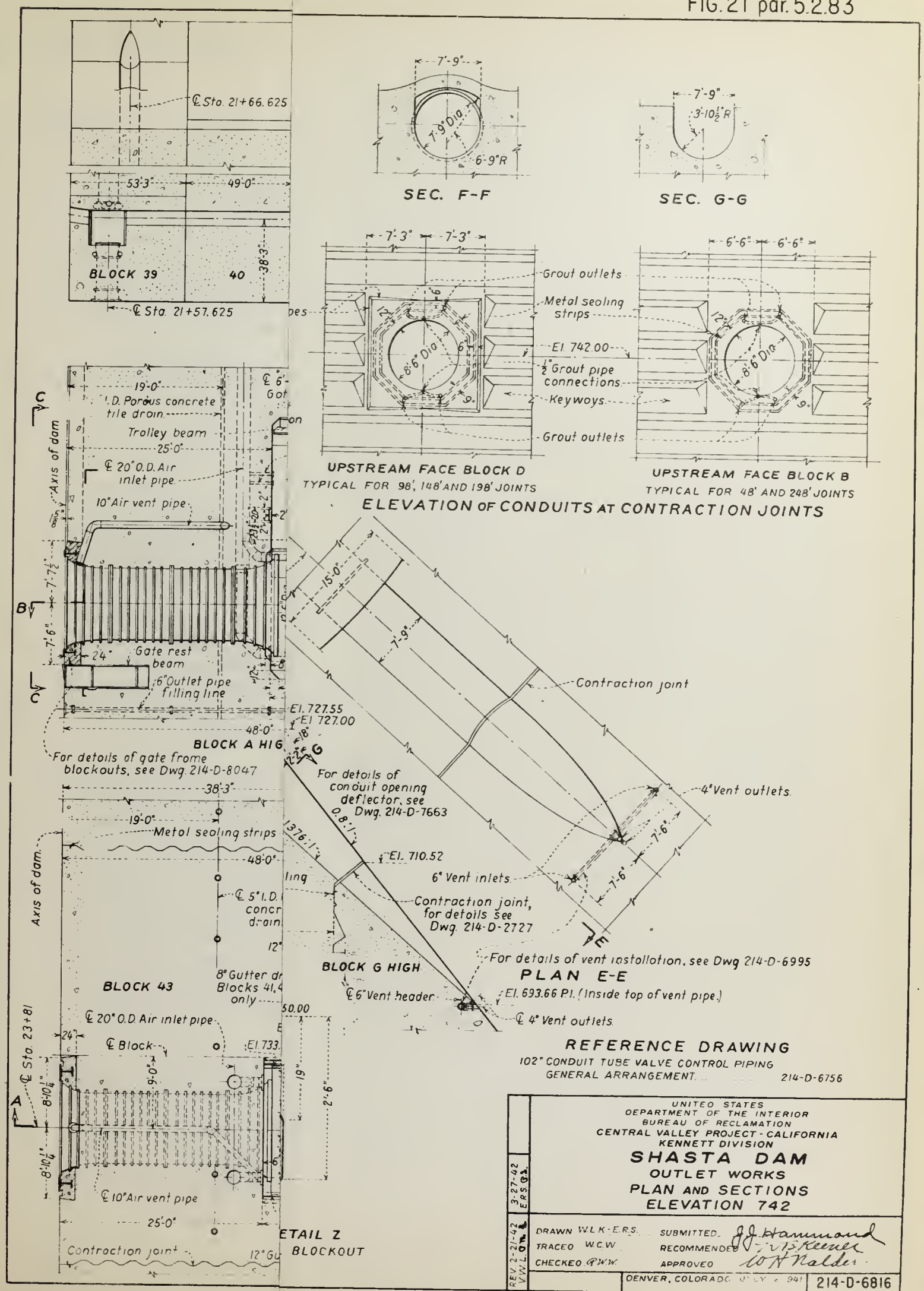
DIVERSION REQUIREMENTS

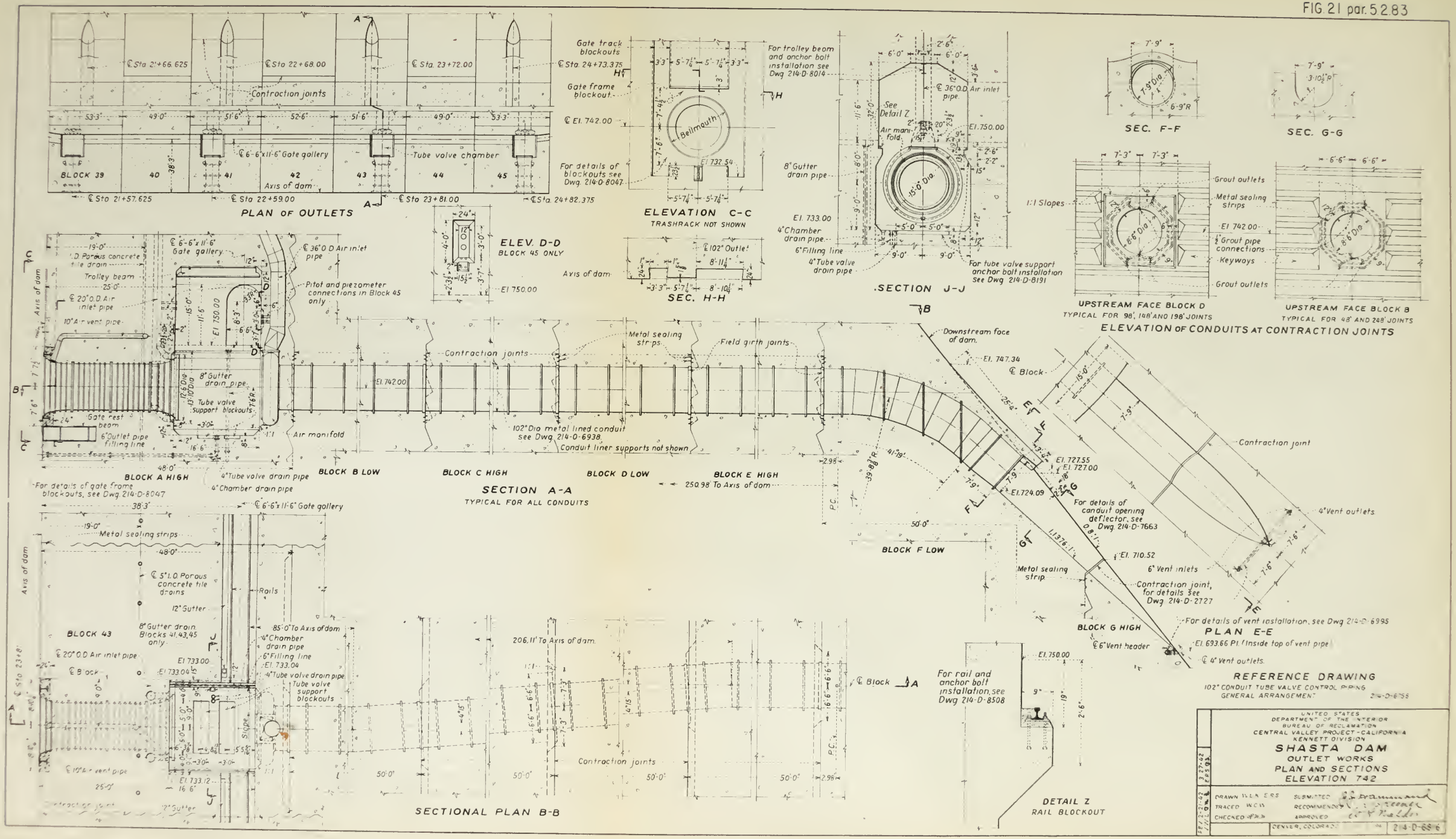
D. Topographical conditions at the site may require that the river be diverted through the dam during construction. Depending on the expected flow during the construction period, it may be necessary to increase the normal number of outlets. These additional outlets may be plugged upon completion of the dam, or may be fitted with suitable gates and left to be used in an emergency or for unwatering of the reservoir at some future date.

LOCATION

.83 In general, river outlets are located close to the river channel in order to minimize channel excavation downstream,

FIG. 21 par. 5.2.83




PLAN OF OUTLETS
Contraction joints
℄ 6'-6" x 11'-6" Gate gallery
Tube valve chamber
BLOCK 39
40
41
42
43
44
45
Axis of dam
℄ Sta 21+57.625
℄ Sta 22+59.00
℄ Sta 23+81.00
℄ Sta 24+82.375
ELEVATION C-C
TRASHRACK NOT SHOWN
Gate track blockouts
℄ Sta. 24+73.375
Gate frame blockout
℄ El. 742.00
Bellmouth
El 732.54
For details of blockouts see Dwg. 214-D-8047
SECTION J-J
For trolley beam and anchor bolt installation see Dwg 214-D-8014
℄ 36" O.D. Air inlet pipe
See Detail Z
Air manifold
El. 750.00
8" Gutter drain pipe
15'-0" Dia.
El. 733.00
4" Chamber drain pipe
6" Filling line
4" Tube valve drain pipe
For tube valve support anchor bolt installation see Dwg 214-D-8191
SEC. F-F
SEC. G-G
Grout outlets
Metal sealing strips
1:1 Slopes
El. 742.00
½" Grout pipe connections
Keyways
UPSTREAM FACE BLOCK D
TYPICAL FOR 98', 148' AND 198' JOINTS
UPSTREAM FACE BLOCK B
TYPICAL FOR 48' AND 248' JOINTS
ELEVATION OF CONDUITS AT CONTRACTION JOINTS
ELEV. D-D
BLOCK 45 ONLY
SEC. H-H
℄ 102" Outlet
Axis of dam
El 750.00
℄ 6'-6" x 11'-6" Gate gallery
℄ 36" O.D. Air inlet pipe
Pitot and piezometer connections in Block 45 only
Trolley beam
℄ 20" O.D. Air inlet pipe
10" Air vent pipe
Contraction joints
Metal sealing strips
Field girth joints
Downstream face of dam.
El. 747.34
℄ Block
8" Gutter drain pipe
Tube valve support blockouts
Gate rest beam
6" Outlet pipe filling line
Air manifold
102" Dia metal lined conduit see Dwg. 214-D-6938
Conduit liner supports not shown
BLOCK A HIGH
BLOCK B LOW
BLOCK C HIGH
BLOCK D LOW
BLOCK E HIGH
250.98' To Axis of dam
BLOCK F LOW
BLOCK G HIGH
For details of gate frame blockouts, see Dwg. 214-D-8047
4" Tube valve drain pipe
4" Chamber drain pipe
SECTION A-A
TYPICAL FOR ALL CONDUITS
Contraction joint
4" Vent outlets
El. 727.55
El. 727.00
El. 724.09
For details of conduit opening deflector, see Dwg. 214-D-7663
El. 710.52
6" Vent inlets
Metal sealing strip
Contraction joint, for details see Dwg 214-D-2727
For details of vent installation, see Dwg 214-D-6995
PLAN E-E
El. 693.66 Pt. (Inside top of vent pipe)
℄ 4" Vent outlets.
℄ 6" Vent header
REFERENCE DRAWING
102" CONDUIT TUBE VALVE CONTROL PIPING GENERAL ARRANGEMENT
214-D-6755
Metal sealing strips
℄ 5" I.D. Porous concrete tile drains
12" Gutter
Rails
BLOCK 43
8" Gutter drain. Blocks 41, 43, 45 only
85'-0" To Axis of dam
4" Chamber drain pipe
6" Filling line
El. 733.04
4" Tube valve drain pipe
Tube valve support blockouts
℄ 20" O.D. Air inlet pipe
El 733.00
℄ Block
Slope
206.11' To Axis of dam.
Contraction joints
SECTIONAL PLAN B-B
For rail and anchor bolt installation, see Dwg 214-D-8508
DETAIL Z
RAIL BLOCKOUT
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT - CALIFORNIA
KENNETT DIVISION
SHASTA DAM
OUTLET WORKS
PLAN AND SECTIONS
ELEVATION 742
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO
214-D-6556

(.83) and, in order to provide for the release of water at all times, their intakes will be located below maximum drawdown of the reservoir for other uses. When several outlets are provided, they may all be placed at the same elevation or in tiers, depending on discharge requirements at various elevations, space available in the section of the dam through which they pass, or, in some cases, depending on their use for river diversion during the construction period. Considerations involving type of control, gate operating conditions, channel conditions downstream, and relative costs may determine whether outlets will be located in the spillway section of the dam or in the non-overflow section close to the spillway. When outlets are located in the spillway, the flow is usually controlled from galleries within the dam by gates or valves located close to the entrance of the conduit. When outlets are located in the non-overflow portion of the dam, the flow is usually controlled by valves, at the downstream end of the conduit by valves, a location that is better suited for operation at partial openings without development of excessive turbulence or less than atmospheric pressure in the conduit. If the outlets discharge in the sloping face of the spillway, the discharge end of the conduit is turned downward to improve flow characteristics in the outlets and to deflect the jet along the spillway face with minimum interference with flow over the spillway, as illustrated in Figure 21.

LOCATION (CONT.)

.84 The general details of operation and design of canal outlets are similar to those for river outlets. The number and size will depend on the capacity requirements with the reservoir at a predetermined elevation and on the degree of control required as the elevation of the reservoir fluctuates. Their location through the dam is controlled by the location and elevation of the canal. Canal outlets usually include the design of a stilling basin in order that the relatively high discharge velocities are reduced to safe velocities consistent with the design of the canal. Typical canal outlet installations are illustrated in Figure 3.

CANAL OUTLETS

.85 Once the size of the water passageway or penstock is determined, the general considerations that apply to the design of power outlets parallel those which apply to other outlets. More care may need to be exercised, however, to reduce head losses to a minimum, consistent with cost. A complete discussion of the factors and problems involved in the design of penstocks is given in Chapter 6.2.

POWER OUTLETS

DETERMINATION OF SIZE

(.85) For relatively short penstocks, as when the powerhouse is integral with the dam, the most important consideration in determining size is to provide for the passage of a regulated flow of water at suitably limited velocity without risk of waterhammer or pressure surges in the conduit. For long penstock lines, size is usually based on economic studies. The most economical diameter would be that for which the total annual cost, annual fixed charges on initial investment plus annual cost of power lost in friction, is a minimum. This diameter should then be adjusted to meet speed regulation characteristics of the turbine, or else means for controlling pressure waves, such as pressure regulating valve or surge tank, should be inserted in the line.

OUTLET ELEMENTS

.86 As indicated in the foregoing discussion, all types of outlet works are generally similar and subject to the same general design considerations. Some design factors, however, will be relatively more important and have greater effect on one type of outlet than on another, which will result in differences in the details of corresponding elements of each type of outlet. For design purposes outlet works may be divided into the following elements: conduit or water passageway; trashrack structure; gates or valves and their operating equipment; structures to house, support, and protect the operating equipment; and hydraulic structures at the exit to dissipate the surplus energy of the issuing flow.

CONDUIT

.87 The design of the water passageway, conduit, or penstock through the dam is affected by the head, velocity of flow, type of control, and cost. The shape may be rectangular or round, or may change from one section to the other depending on size and type of headgate or on type and location of control equipment. The surface of the conduit may be steel-lined, unlined, or lined for only a portion of its length, depending on hydraulic conditions.

ENTRANCE

A. Abrupt changes in the cross-section of the conduit or penstock, and any projections into the water passageway such as gate frames, create disturbances in the flow which increase in violence as the head and velocity increase. Such conditions reduce the capacity of the outlet and often produce harmful effects on the control equipment and walls of the conduit, and in power outlets reduce the effective head on the turbines. These effects can be minimized by shaping the

(.87A)

intake to conform to the shape of a jet issuing from a standard orifice and by providing smooth and gradual transitions from the inlet through the control. In large conduits and penstocks, the entrance often is rectangular in order to reduce the size of the required headgate, and a transition is required from the square entrance section to the round control and conduit section. It is desirable that the centerline of the intake be made normal to the upstream face of the dam. If the upstream face is battered, and the control gates are so located that the control section of the conduit must be horizontal, a reducing elbow is required immediately below the bell-mouth entrance section. Care must be exercised in the choice of radii of curvature to avoid negative pressures at the inner side of the elbow. ENTRANCE (CONT.)

B. The exit flow conditions present problems which can be solved only by sound engineering judgment supported by results of model tests. The design of energy dissipators when the conduit discharges directly into the river channel or canal is discussed in Paragraph 5.2.84. When the conduit discharges from the spillway face, and stream-bed conditions and depth of tailwater prohibit free jet discharge, the end of the conduit is deflected downward to force the emerging jet to flow along the downstream face of the dam. This arrangment minimized spray and riverbed erosion, and the bucket at the toe of the dam functions as an energy dissipator for the outlets as well as for the spillway. In order to maintain positive pressures throughout the conduit and to assure a smooth emerging jet which will conform to the trough section at the end of the outlet, a cone reducer is placed immediately downstream from the elbow. Examples of deflected conduits for river outlets in spillway sections of dams are illustrated in Figure 21. EXIT

C. The temperature differential between the relatively cool water passing through the conduit and the relatively warm concrete mass will produce tensile stresses in the concrete in the immediate vicinity of the conduit. Also, the opening through the dam formed by the conduit will alter the distribution of stress in the dam in the vicinity of the conduit, tending to produce tensile stresses in the concrete at the top and bottom of the conduit. The tensile stresses developed due to these two conditions, corrected by the effect of full hydrostatic pressure, REINFORCEMENT

(.87C)

will require the placing of steel reinforcement in the concrete around the conduit. The magnitude of these stresses and the method of their determination are given in Technical Memorandum No. 457, "Stresses and Reinforcement Steel Around Circular Openings in Concrete Dams with Application to Grand Coulee Dam."

TRASHRACK STRUCTURE

.88 Trashracks are used to keep out of the conduit any objectionable large debris which might damage or otherwise render inoperative the control equipment or turbines. The Bureau has developed and used several types of structures for this purpose, depending upon type of outlet works and accessibility for cleaning and maintenance, as discussed in Chapter 6.9. These structures may be rectangular or may approach a semicircle in shape, depending on the size of conduit, head, velocity of flow, and quantity of debris to be expected. It is desirable that the trashrack structure be carried to the top of the dam in order to facilitate cleaning. Depending on location of the outlet and seasonal fluctuations of the reservoir elevation, trashracks may terminate at an elevation where reservoir drawdown will permit their cleaning at least once a year.

DESIGN LOAD

A. The load on the trashrack structure is normally quite small, but as the rack becomes clogged with debris a head differential is created which approaches full hydrostatic head when the trashbars are completely choked. Since this condition is only a remote possibility, Bureau practice is to design the structure to withstand a head differential of 50 percent of the total hydrostatic head, with maximum value of 40 feet. The trashbar sections are then designed to fail at a somewhat lower pressure.

TRASHBARS

B. The trashbars consist of relatively thin flat steel bars set on edge and spaced from 2 to 6 inches apart depending on the type of equipment they protect. Present practice is for a spacing of 5 inches in outlet works containing high pressure slide gates, and for closer spacing in trashracks protecting control valves and powerplant equipment. The bars are usually assembled into sections or panels and held in place by grooves or guides in the trashrack structure. Bars for power outlets may be rounded at the upstream edge or otherwise streamlined in order to improve hydraulic conditions and minimize head losses.

.89 Control devices may be divided into two general classes, gates and valves. Gates normally operate either in the fully opened or the closed position and, prior to the development of specially designed gates for high-head operation, were usually associated with low-head installations. Valves are designed to operate at various openings, permitting close regulation of the flow, and are usually associated with high-head installations. Standard commercial gates and valves are available and may be adequate for low-head installations involving relatively small discharges. High-head installations, however, usually require specially designed equipment, depending primarily on the location of the control with respect to the dam. A detailed description of the various types of gates and valves, their uses, limitations, and operating characteristics is given in Chapter 6.3. CONTROL EQUIPMENT

A. Several features combine to make the downstream end of the conduit the most desirable location for the control. This location permits the installation of a regulating valve to obtain close regulation of the flow, and permits the great amount of energy in the discharge to be dissipated outside of the conduit. By eliminating gate operation at the entrance or within the conduit, better flow conditions are maintained throughout the water passage and the principal cause of cavitation and vibration is removed. Finally, locating the control entirely free of the dam makes the entire unit more readily accessible for repairs or, if necessary, for replacement. When outlets are located in the spillway section of the dam, the control must, of necessity, be located upstream, usually in the conduit where operation and servicing can be accomplished from galleries. The throttling of flow at this location in order to achieve regulation may create violent disturbance in the flow which can damage the gate and cause pitting in the lining of the conduit. A gate designed to operate in the full open position will cause least disturbance to flow and is best suited for this location. When necessary at this location to install a control to run partially open, valves such as tube valves are preferred, which are especially designed to cause the least disturbance to flow. LOCATION

B. Experience has shown that it is necessary to provide for the admittance of large quantities of air to the conduit immediately downstream from the high-pressure gate in order to eliminate the destructive pounding AIRVENTS

(.89B) and cavitation accompanying high-velocity flow. The amount of air required has been determined from a study of data derived from many installations operating under varying conditions. A diagram of the required size of air-vents for various conditions of head and gate sizes is given in Figure 22.

EMERGENCY GATES

C. High-pressure gates are often installed in the outlets in addition to the service control, in order to provide an emergency means of closing the conduit. These gates are located upstream from the control and may consist of a tractor or coaster gate to close the entrance to the conduit, or a duplicate control gate operated from the gallery.

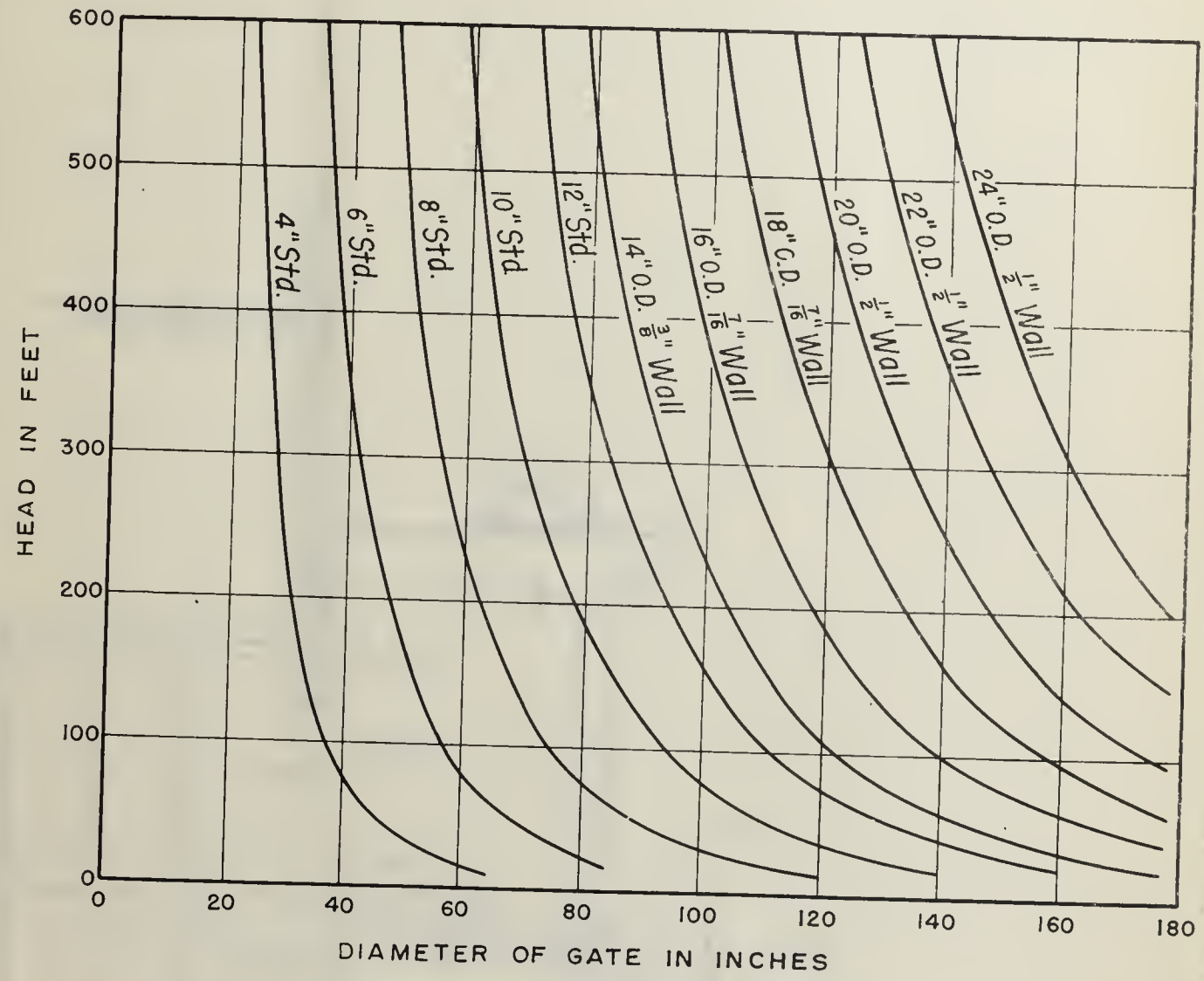
BULKHEAD GATES

D. Some means is necessary of closing the entrance to the conduit in order to permit unwatering of the water passage for inspection and repair of the control equipment. For low-head developments, stop logs or a sliding bulkhead gate may be used. For high heads, wheel-type gates, designed to operate under full hydrostatic head and serving also as emergency gates, or bulkhead gates designed to operate only under balanced pressure, may be used. Bulkhead gates will require a means of bypassing water from the upstream face to the conduit in order to balance the pressure on both sides of the gate before it is raised. While this provision is not essential to the operation of the wheel-type gates, it is desirable in order to facilitate operation and reduce wear on the moving parts. Adequate air passageways should also be provided immediately downstream from such bulkhead or emergency closure gates, both to prevent air from being trapped and compressed when water is admitted to the conduit through the filling bypasses preparatory to opening the gates under balanced pressure, and to reduce or eliminate vacuum pockets during emergency closure.

VALVE HOUSE

.90 When control equipment is located at the exit from the conduit, a valve or control house is usually provided to house the valve and operating mechanisms and to provide space and facilities for repairs. The substructure of the valve house provides a concrete anchor for the end of the conduit and a support for the valve. The superstructure provides covered space for the valve operating equipment, working space for dismantling the unit, and furnishes support for hoisting equipment. No standard valve house design is established, each structure being

FIG. 22. par. 5.2. 89



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

SINGLE AIR VENT PIPE SIZES FOR RING-FOLLOWER AND PARADOX GATES

BY G.R.R	APRIL 25, 1946
APR. C.R.	MD-DT-3

COPY OF DWG. X-D-1882

FIG. 23 par. 5.2.90

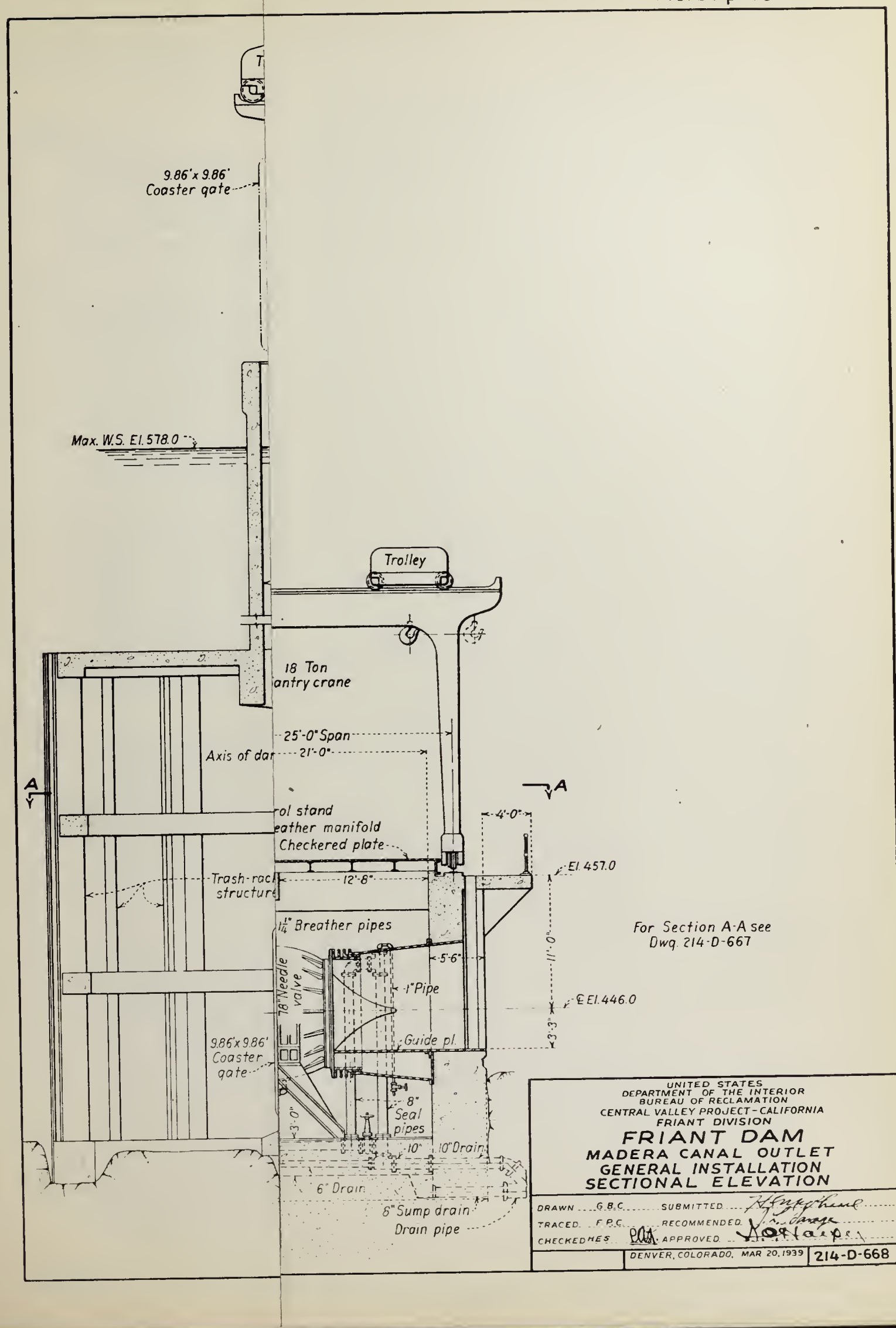
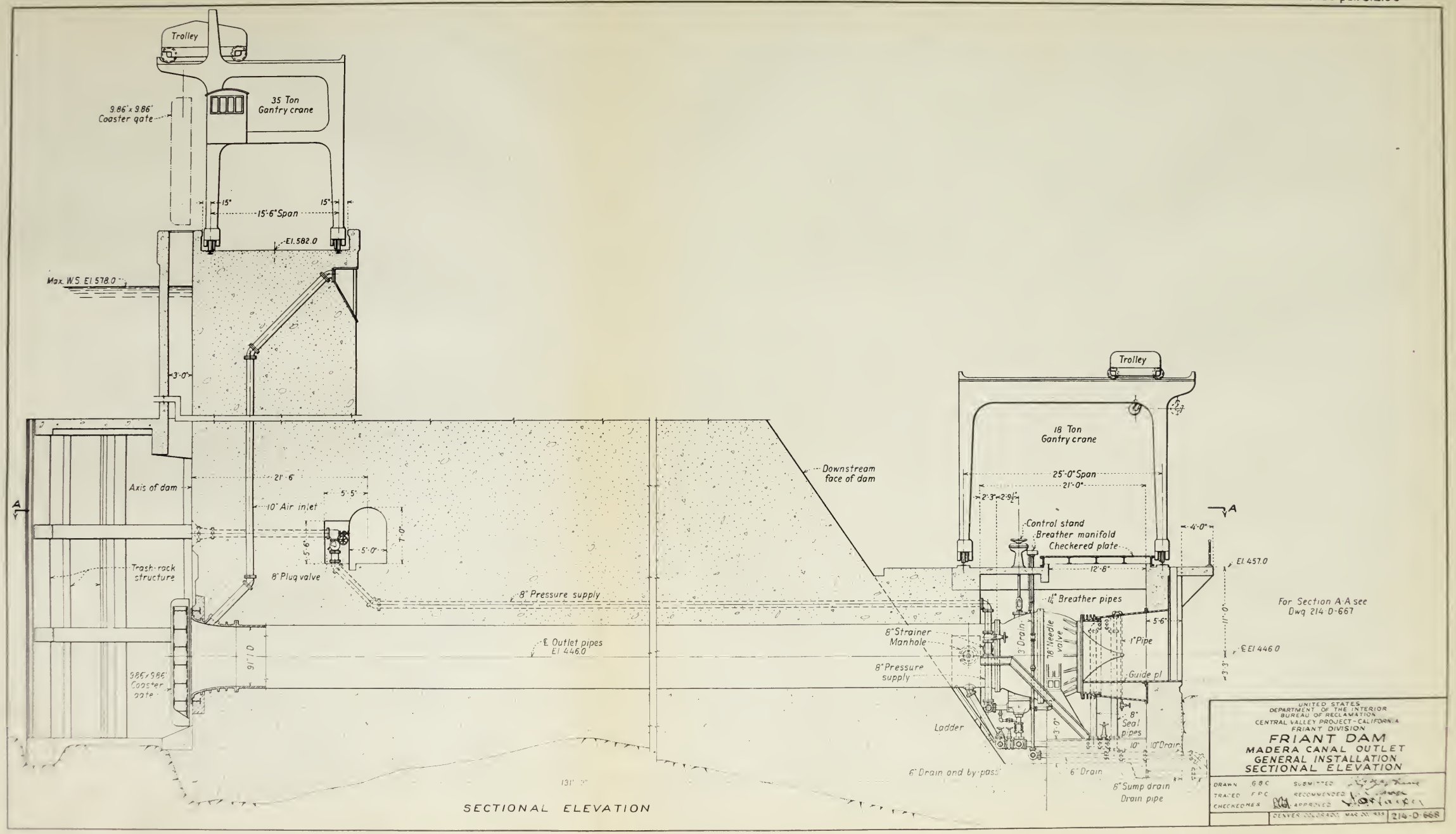


FIG. 23 par. 5.2.90



SECTIONAL ELEVATION

(.90) designed to suit the particular installation and to satisfy conditions of operation. When exposure conditions are not severe, the superstructure may be omitted, and the valves serviced by gantry cranes, as was done at Friant Dam, illustrated in Figure 23.

ENERGY DISSIPATOR

.91 The discharge from the outlet, whether from gates, valves, or free-flow conduit, will usually emerge at a relatively high velocity. Some means of expending the energy of the flow is usually provided in order to prevent scour of the bed and banks of the river channel or canal which would result in possible damage to the outlet structure or the dam itself. This may be accomplished by constructing a stilling basin or energy dissipator immediately downstream from the outlet in order to establish safe flow conditions in the outlet channel. The exact effect of the energy dissipator on the flow is difficult to predict and cannot be determined by theoretical calculations. Model tests of various designs should therefore be conducted and studied in order to choose a design whose proper functioning is assured under all conditions. A more complete discussion of the problems involved in energy dissipation is given in Paragraph 5.2.76, and general rules for design based on model studies for several projects are given in Chapter 5.6.

TOWERS

.92 One or more towers may be included in the appurtenant structures for the purpose of providing sheltered entrances to and space for mechanical equipment of elevators and hoists which operate between the top of the dam and the galleries. Separate towers may also be constructed to furnish utility, storage, office, and concession space depending on the relative magnitude of the project and the expected interest of the public.

ARCHITECTURAL TREATMENT

Towers on a dam constitute entrances to the interior of the structure and as such are focal points of interest. Architectural considerations for their arrangement and design therefore become important. The objective should be simplicity and an effectiveness which blends with the massiveness of the dam and gives a pleasing and finished appearance to the structure. Architectural treatment of decorative details may be influenced by the history of the project or of the locality and, as illustrated in Figure 24, sculptured cast-concrete panels and bronze memorial plaques depicting graphically the historical motif and function of the project may be included. Figures 25 and 26 show structural drawings of typical tower

(.92)

layouts and designs for a dam given somewhat less publicity, yet they contain the elements of simplicity and effectiveness.

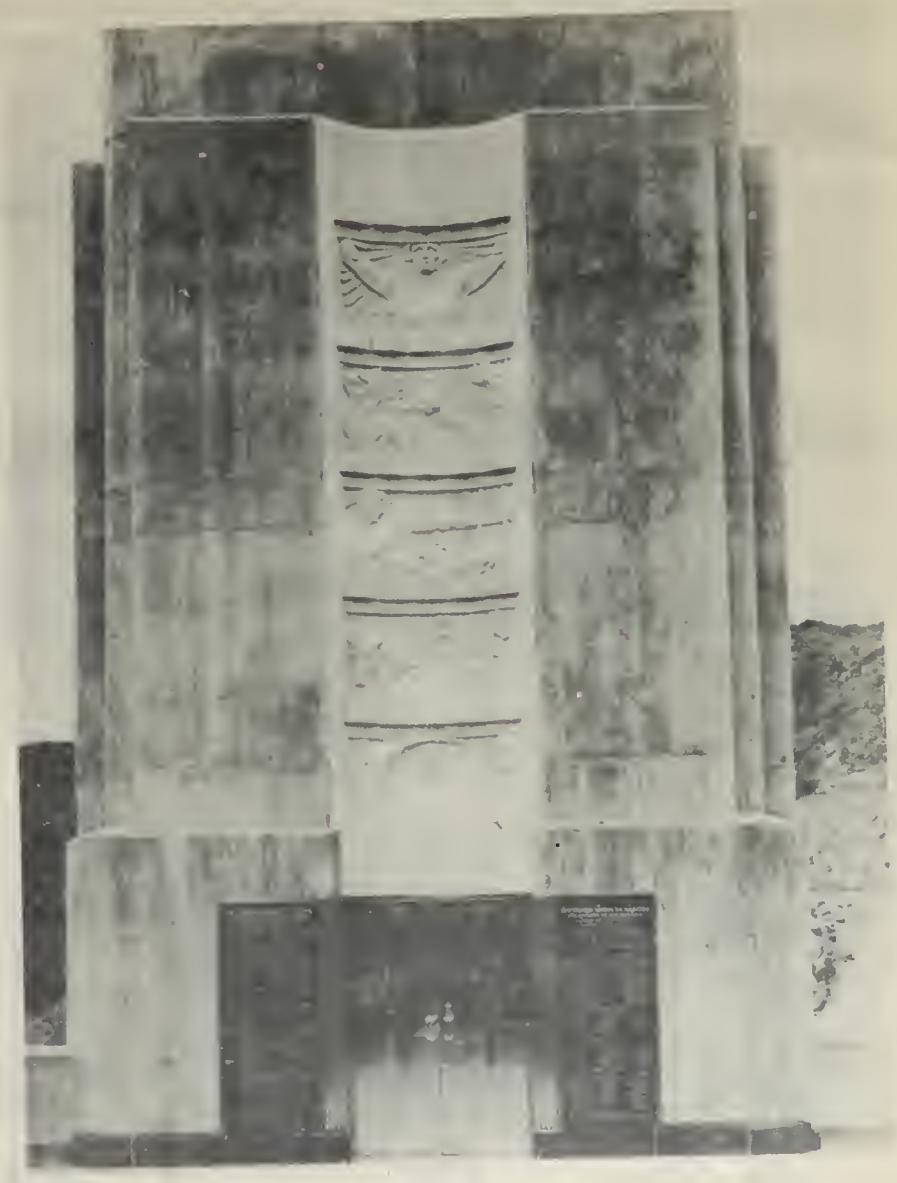
SPILLWAY BRIDGE

.93 A bridge over the spillway is required when a highway has been routed over the dam or when bulkhead gates for river outlets or spillway crest gates require the use of a traveling crane for their operation. One of several types of bridges, either of steel or reinforced-concrete construction, may be chosen depending on length of span, head restrictions or requirements above the crest, or purely aesthetic reasons. When no highway crosses the dam, the spillway bridge may consist simply of two steel girders or reinforced-concrete beams supporting the crane rails and walkway. When the bridge is to be used for a highway, more care is given to its appearance. Architectural treatment will be based on the size and type of dam, size and type of other appurtenant structures, local topography, and the type of bridge itself, in order to produce a design which blends pleasingly with the entire structure.

DESIGN CRITERIA

Design criteria for highway bridges will usually conform to the Standard Specifications adopted by the American Association of State Highway Officials, modified to satisfy local regulations and any particular requirement of the project. The width of the roadway is usually 30 feet curb to curb plus a 6-foot walkway. Girders, floor beams, and floor slab are designed to support the loading classification given in the Standard Specifications consistent with the class of traffic to use the bridge. Usually the traffic load used will not be less than the H-20 classification. Critical design loads may, however, be governed by special loadings during the construction period of the project. Large and heavy powerplant equipment hauled on specially constructed trailers by heavy tractors may produce stresses far in excess of those for normal highway traffic. If the bridge is also to be used for servicing gates, the loading imposed by the weight of the crane, plus the force necessary to lift the heaviest gate, plus 25 percent impact must be used in addition to normal traffic loads. Walkways are usually cantilevered from a main girder or the road slab. Design loads usually include the dead load of walk, slab, and guardrail, a live load of 100 pounds per square foot of walkway, and a horizontal live load of 100 to 150 pounds per linear foot of guardrail applied at the top of the rail. Other considerations

VIEW OF TOWERS FROM DOWNSTREAM

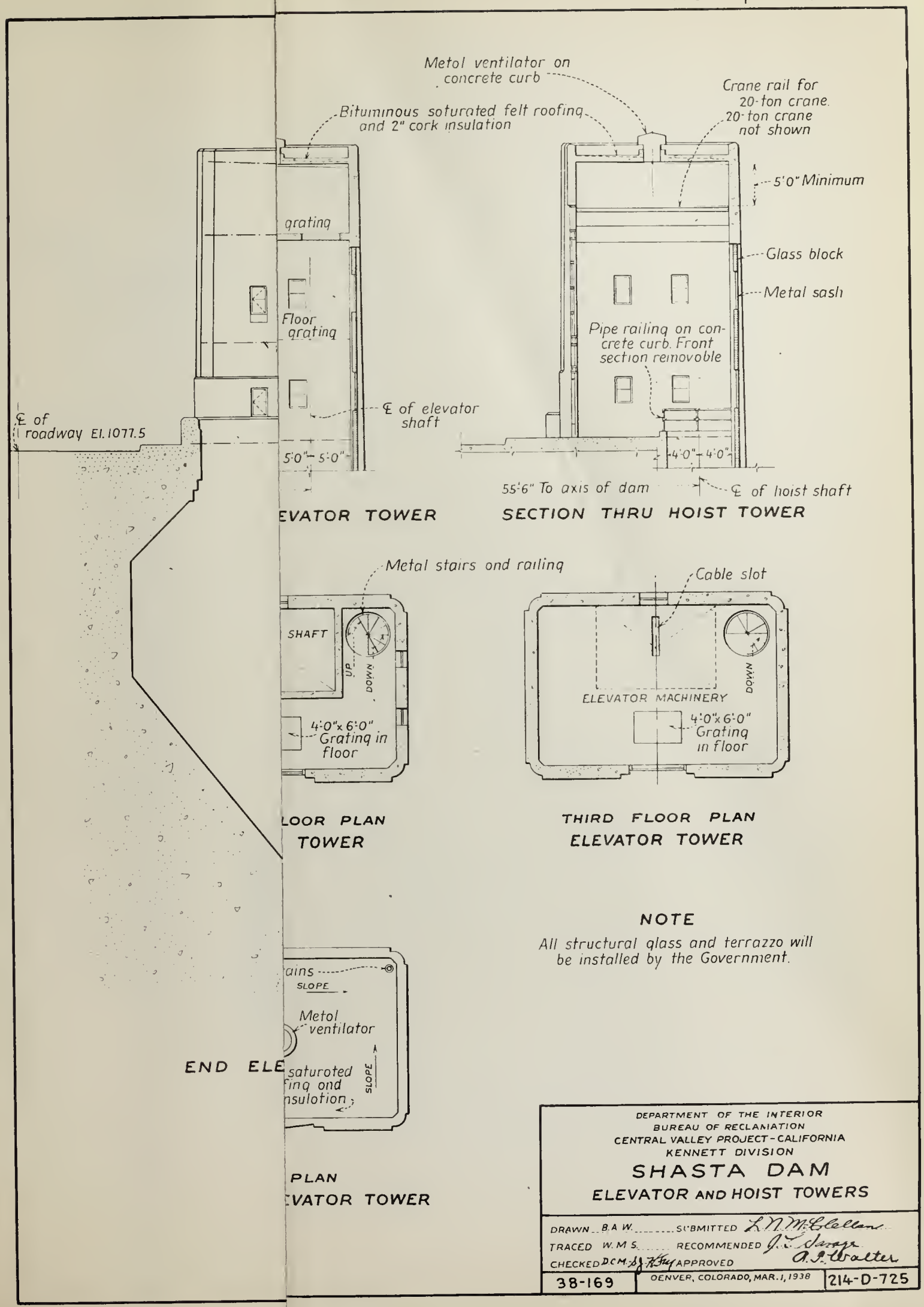


ENTRANCE SHOWING PLAQUES AND BAS-RELIEFS

ARCHITECTURAL TREATMENT OF ELEVATOR TOWERS, BOULDER DAM, ARIZONA

FIG. 24 par. 5.2.92

FIG. 25 par. 5.2.92



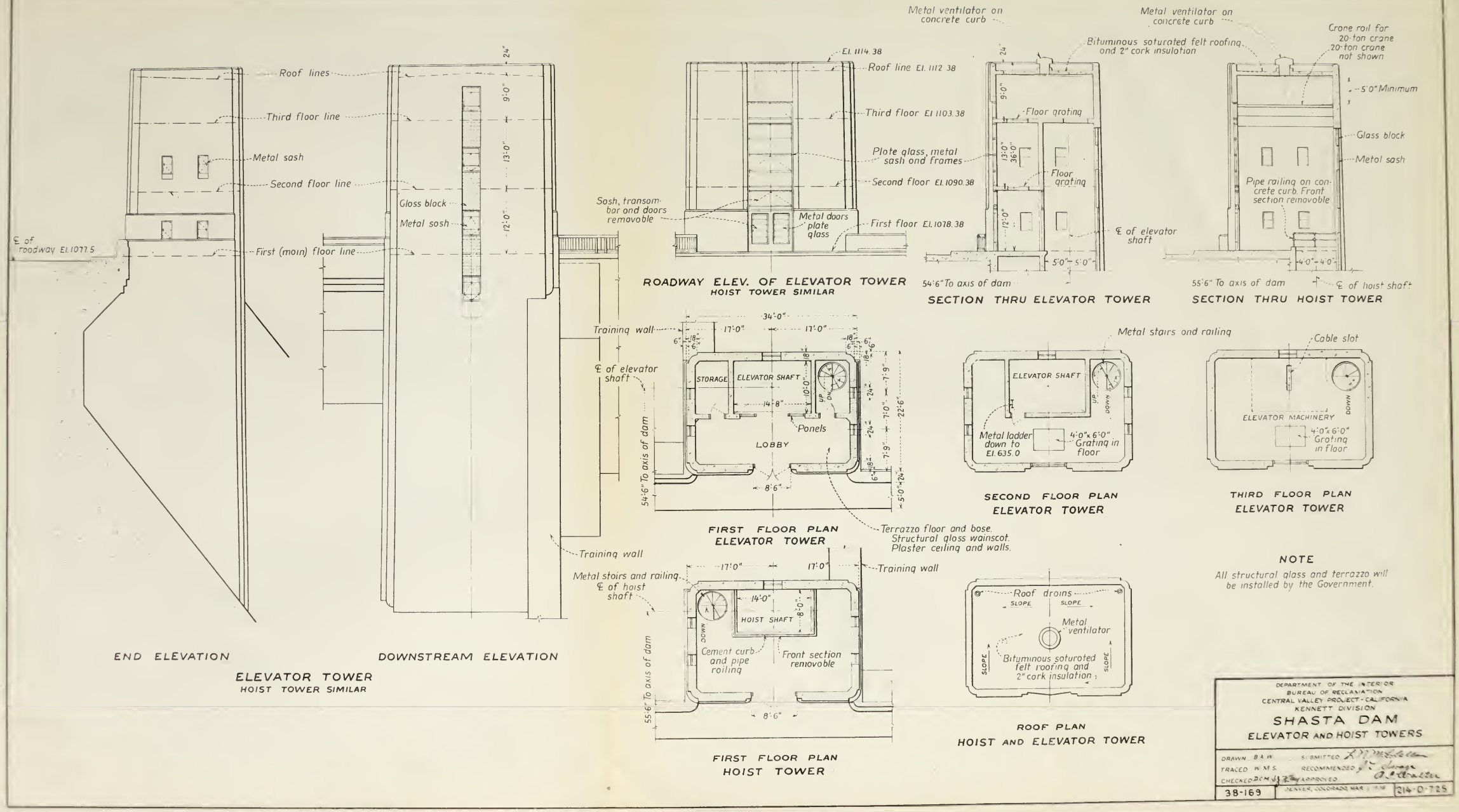
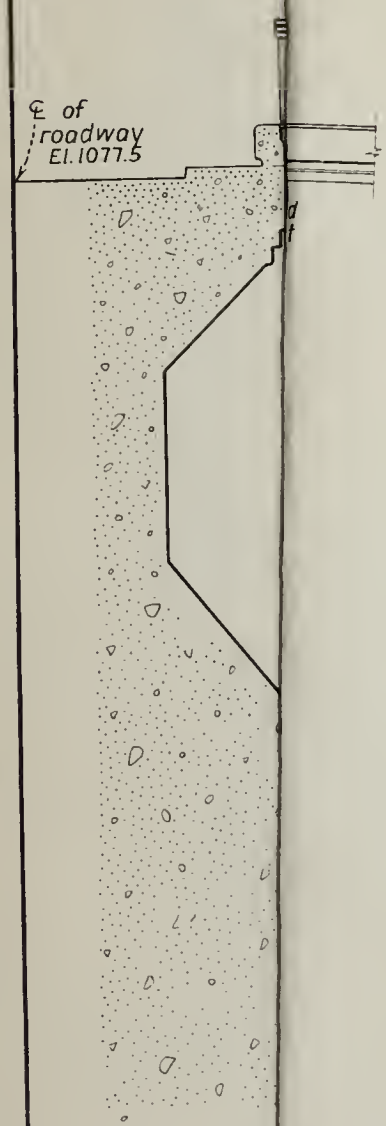
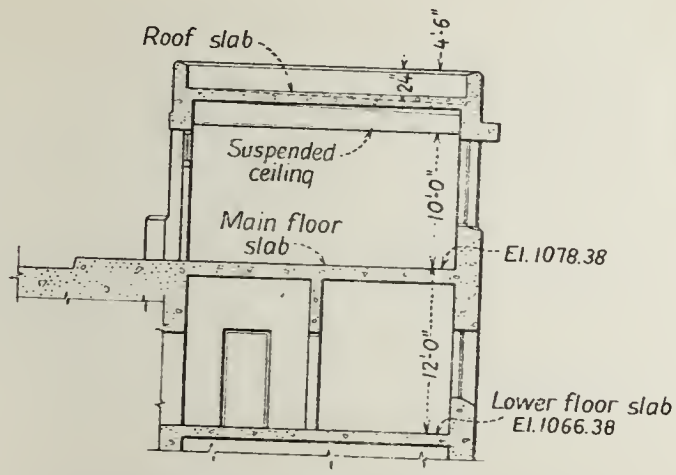
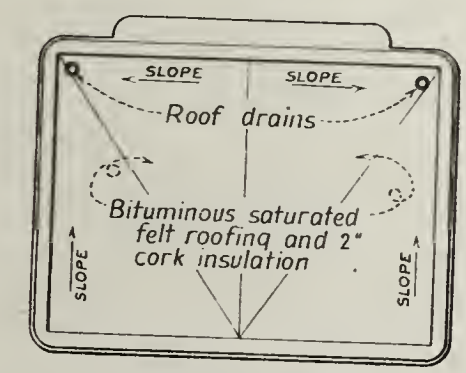

Roof lines
Third floor line
Metal sash
Second floor line
Gloss block
Metal sash
First (main) floor line
℄ of roadway El. 1077.5
2'-4"
9'-0"
13'-0"
12'-0"
END ELEVATION
DOWNSTREAM ELEVATION
ELEVATOR TOWER
HOIST TOWER SIMILAR
El. 1114.38
Roof line El. 1112.38
Third floor El. 1103.38
Plate glass, metal sash and frames
Second floor El. 1090.38
First floor El. 1078.38
Sash, transom bar and doors removable
Metal doors plate glass
ROADWAY ELEV. OF ELEVATOR TOWER
HOIST TOWER SIMILAR
Metal ventilator on concrete curb
Bituminous saturated felt roofing and 2" cork insulation
Floor grating
℄ of elevator shaft
5'-0"
54'-6" To axis of dam
SECTION THRU ELEVATOR TOWER
Metal ventilator on concrete curb
Crane rail for 20-ton crane 20-ton crane not shown
5'-0" Minimum
Glass block
Metal sash
Pipe railing on concrete curb. Front section removable
4'-0"
55'-6" To axis of dam
℄ of hoist shaft
SECTION THRU HOIST TOWER
Training wall
℄ of elevator shaft
34'-0"
17'-0"
STORAGE
ELEVATOR SHAFT
14'-8"
10'-0"
UP
DOWN
Panels
LOBBY
8'-6"
54'-6" To axis of dam
22'-6"
5'-0"
FIRST FLOOR PLAN
ELEVATOR TOWER
Terrazzo floor and base. Structural glass wainscot. Plaster ceiling and walls.
Metal stairs and railing
ELEVATOR SHAFT
Metal ladder down to El. 635.0
4'-0" x 6'-0" Grating in floor
SECOND FLOOR PLAN
ELEVATOR TOWER
Cable slot
ELEVATOR MACHINERY
4'-0" x 6'-0" Grating in floor
THIRD FLOOR PLAN
ELEVATOR TOWER
NOTE
All structural glass and terrazzo will be installed by the Government.
Training wall
Metal stairs and railing
℄ of hoist shaft
HOIST SHAFT
14'-0"
8'-0"
DOWN
Cement curb and pipe railing
Front section removable
55'-6" To axis of dam
FIRST FLOOR PLAN
HOIST TOWER
Roof drains
SLOPE
Metal ventilator
Bituminous saturated felt roofing and 2" cork insulation
ROOF PLAN
HOIST AND ELEVATOR TOWER
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT - CALIFORNIA
KENNETT DIVISION
SHASTA DAM
ELEVATOR AND HOIST TOWERS
DRAWN B.A.W.
TRACED W.M.S.
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
38-169
DENVER, COLORADO, MAR.
214-D-725

FIG. 26 par. 5.2.92





SECTION THRU CONCESSION TOWER
UTILITY TOWER SIMILAR



ROOF PLAN
CONCESSION AND UTILITY TOWERS

NOTES

All stair-(except enclosed stairs below El. 1066.38) shall have terrazzo treads, risers, landings, base and curbs, and aluminum stair railings.

All toilet rooms, stair halls, concession space, first aid room, and women's lobby shall have terrazzo floors and base, structural glass wainscots toilet and shower stalls, and plastered walls and ceilings.

Ranger's office, storage room, and guides room shall have terrazzo floors and base and plastered walls and ceilings.

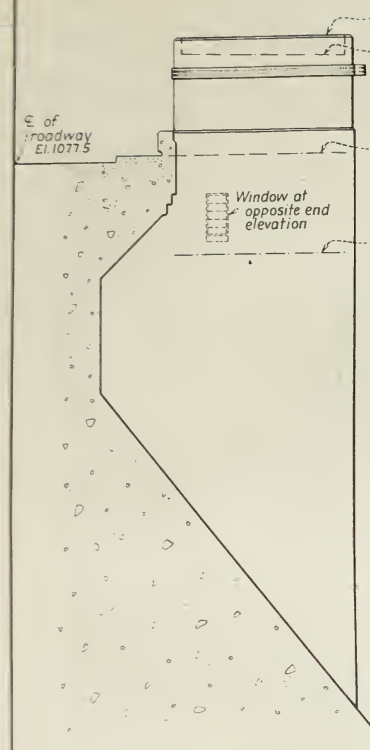
All structural glass, terrazzo, aluminum stair railings, and plumbing fixtures will be installed by the Government.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT - CALIFORNIA
KENNETT DIVISION

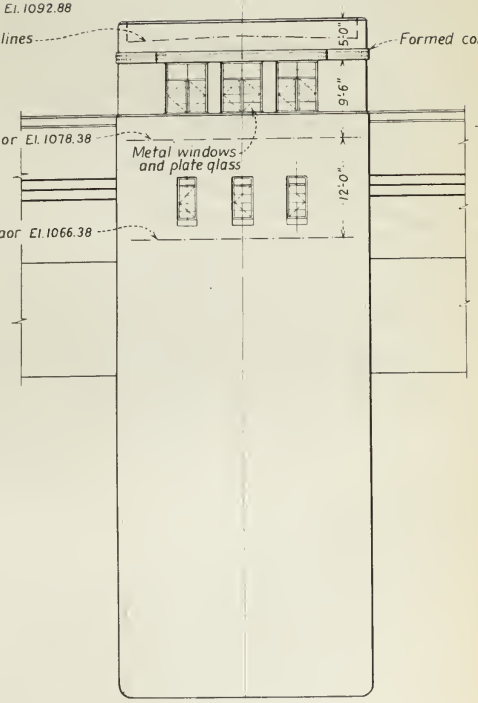
SHASTA DAM
CONCESSION AND UTILITY TOWERS

DRAWN B.A.W. SUBMITTED L.N. McClellan
TRACED W.M.S. RECOMMENDED J.L. Savage
CHECKED D.C.M. APPROVED A.F. Walter

38-170 | DENVER, COLORADO, MAR. 1, 1938 | 214-D-726



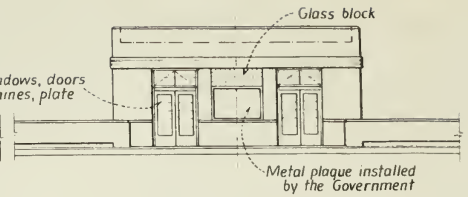
END ELEVATION



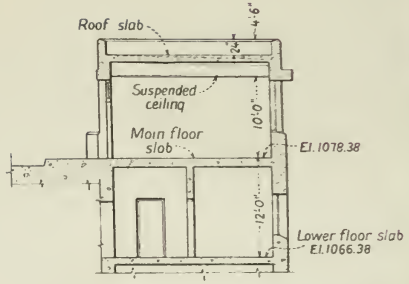
DOWNSTREAM ELEVATION

CONCESSION AND UTILITY TOWERS

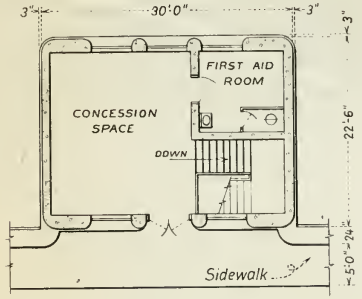
ROADWAY ELEVATION
CONCESSION TOWER



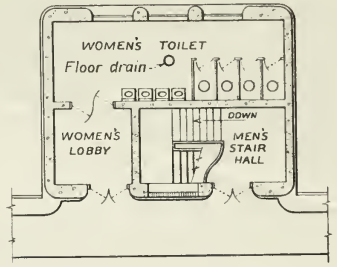
ROADWAY ELEVATION
UTILITY TOWER



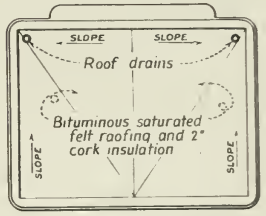
SECTION THRU CONCESSION TOWER
UTILITY TOWER SIMILAR



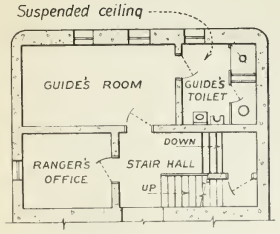
MAIN FLOOR PLAN
CONCESSION TOWER



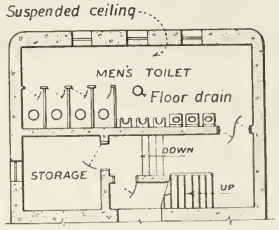
MAIN FLOOR PLAN
UTILITY TOWER



ROOF PLAN
CONCESSION AND UTILITY TOWERS



PLAN AT EL. 1066.38
CONCESSION TOWER



PLAN AT EL. 1066.38
UTILITY TOWER

NOTES

All stair-(except enclosed stairs below El. 1066.38) shall have terrazzo treads, risers, landings, base and curbs, and aluminum stair railings.

All toilet rooms, stair halls, concession space, first aid room, and women's lobby shall have terrazzo floors and base, structural glass wainscots toilet and shower stalls, and plastered walls and ceilings.

Ranger's office, storage room, and guides room shall have terrazzo floors and base and plastered walls and ceilings.

All structural glass, terrazzo, aluminum stair railings, and plumbing fixtures will be installed by the Government.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT - CALIFORNIA
KENNETT DIVISION

SHASTA DAM

CONCESSION AND UTILITY TOWERS

DRAWN B.A.W.	SUBMITTED	
TRACED W.M.S.	RECOMMENDED	
CHECKED BCM 11-36	APPROVED	
38-170		214-D-726

(.93) which must be satisfied include camber, crowning of road slab, adequate storm drains, and roadway lighting facilities. Typical specification drawings for barrel-arch type and girder-type highway bridges are illustrated in Figures 27 and 28.

SERVICE INSTALLATIONS AND EQUIPMENT

.94 Various utilities, equipment, and services will be required for the operation of mechanical and electrical features of the dam, powerhouse, valve house, or other appurtenant structures, or for the convenience of operating personnel and visitors. The amount and type of equipment provided will vary in accordance with the requirements imposed by size, complexity, and function of the various appurtenant structures. The elaborateness of installations for personal convenience will depend on the size of the operating organization and the volume of tourists attracted by the project.

ELECTRICAL

A. Electrical installations include such features as power supply to gate operating equipment, drainage pumps, elevators, cranes, hoists, and lighting systems for use in external lighting as well as in the galleries, tunnels, and appurtenant buildings. The design and layout of the station service generator, electrical circuits, size and type of conduits and cables, transformers, power take-offs, switches, automatic safety devices, etc.. are coordinated with the design of the main features.

MECHANICAL

B. Mechanical equipment and services include such features as overhead traveling cranes in the powerhouse and gate or valve house, gantry cranes on top of the dam for gate operation and trashrack servicing, hoisting equipment for accessories located inside the dam, elevators, compressed-air lines, septic tanks, and gallery ventilating systems.

MISCELLANEOUS

C. Other installations may include vertical slots or recesses in the dam for the storage of bulkhead gates when not in use, or recesses in the canyon wall for housing the gantry cranes. Telephone, water, sewerage, and heating and ventilating systems are also included.

FISHWAYS

.95 The magnitude of the fishing industry in various localities has resulted in Federal, State, and local regulations controlling construction activities which interfere with the upstream migration and natural spawning of anadromous fish. All dams constructed on rivers subject to fish

(.95) runs must be equipped with facilities enabling the adult fish to pass the obstruction on their way upstream, or other methods of fish conservation must be substituted. Since it is required that all facilities for fish protection designed by Federal agencies be approved by the U. S. Fish and Wildlife Service, this agency, and similar State or local agencies, should be consulted prior to the final design stage.

FISH LADDER

A. Several types of fishways have been developed, the most common of which is the fish ladder. In its simplest form, it consists of an inclined flume in which vertical baffles are constructed to form a series of weirs and pools. The slope of the flume is usually ten horizontal to one vertical. The difference in elevation of successive pools and the depth of water flowing over the weirs are made such that the fish are induced to swim rather than leap from pool to pool thereby insuring that the fish will stay in the ladder for its entire length. The size of the structure is influenced by the size of the river, height of dam, size of fish, and magnitude of the run.

FISH LOCK

B. Another type of fishway in common use is the fish lock. This structure consists of a vertical water chamber, gate-controlled entrance and exit, and a system of valves for alternately filling and draining the chamber. Fish locks may be provided with a horizontal screen which can be elevated thereby forcing the fish to rise in the chamber to the exit elevation.

ARTIFICIAL PROPAGATION

.96 Low dams offer little difficulty in providing adequate means for handling fish. High dams, however, create difficulties not only in providing passage for adult fish on their way upstream, but also in providing safe passage for the young fish on their journey downstream. Fish ladders for high dams may require such length and size as to become impracticable. Large reservoirs created by high dams may cause flooding of the spawning areas. The velocity and turbulence of the flow over the spillway or the sudden change in pressure in passing through the outlet works would result in heavy mortality. These difficulties necessitate the substitution of artificial propagation of fish for fishways. In this method, the adult fish are caught on their way upstream and transported to holding ponds where they are held until ready to spawn. The eggs are then transferred to a hatchery and rearing station. When the fingerlings are ready to

FIG. 27 par. 5.2.93

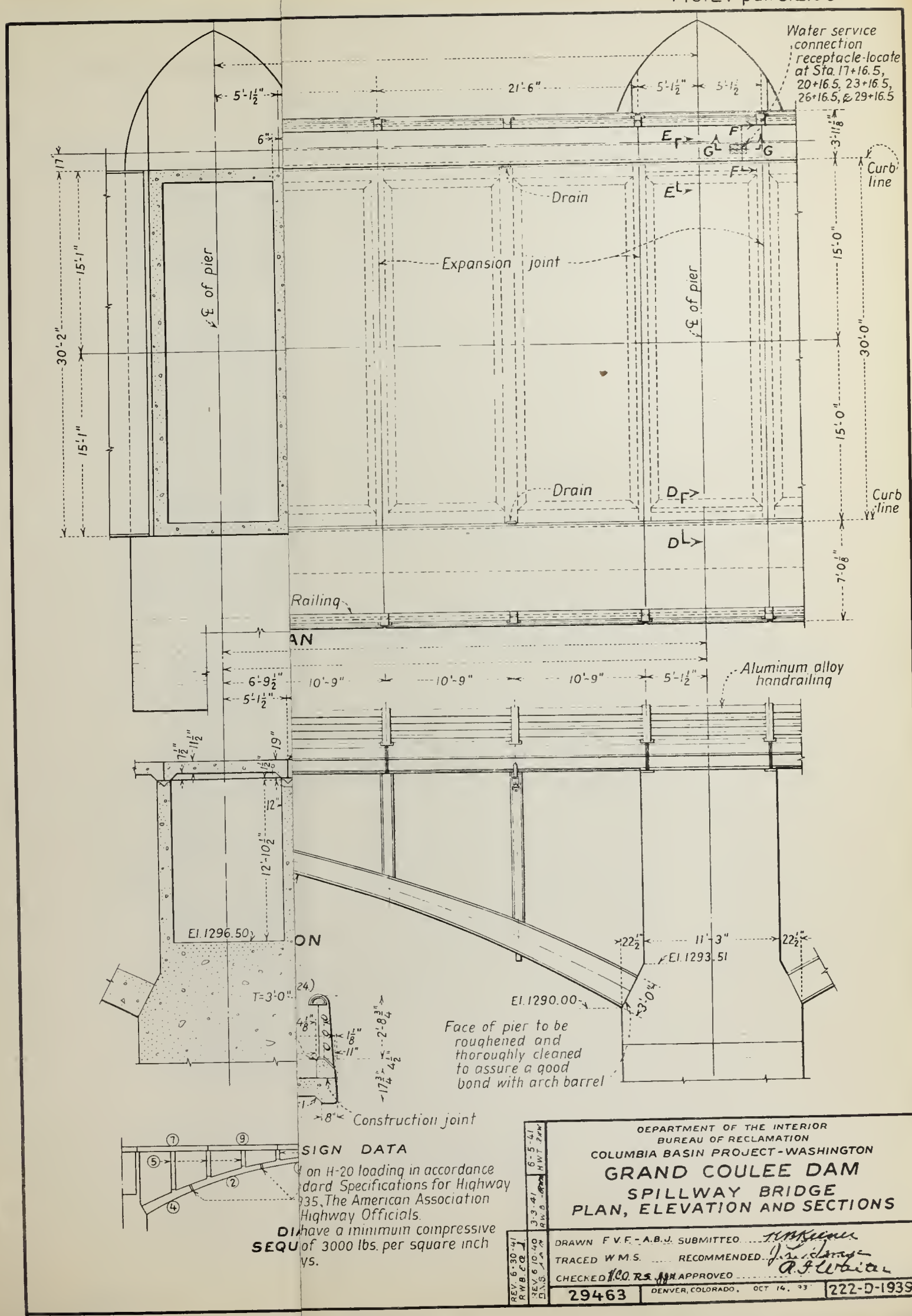
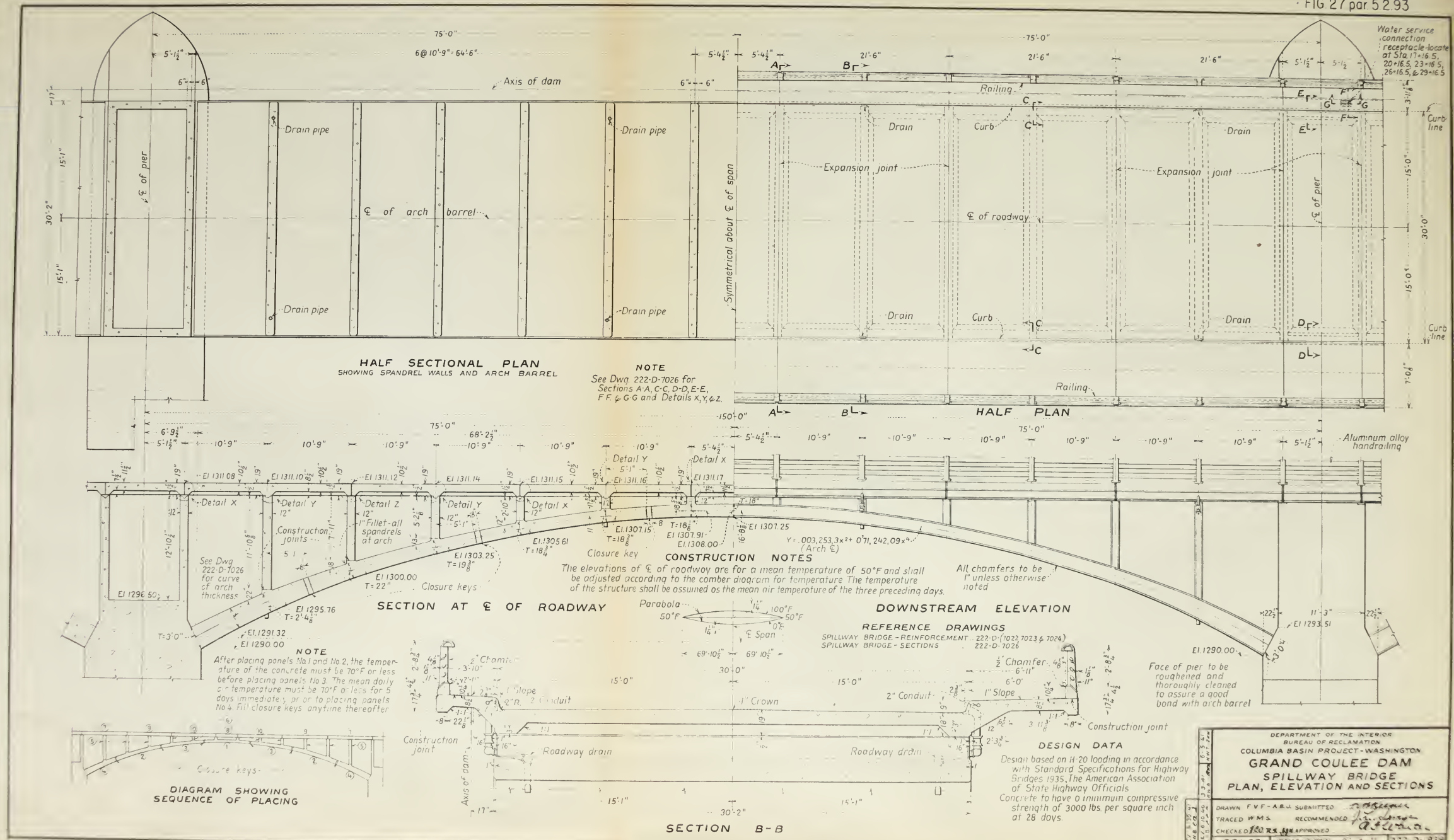


FIG 27 par 5.2.93



(.96)
be released they are transported and liberated in tributary streams which join the main stream below the dam. When these fish are ready to spawn at the end of their life cycle, they seek the point at which they were liberated, thereby establishing future fish runs on streams free from obstructions.

.97 The widespread publicity given to the construction of major Bureau of Reclamation projects has aroused public interest, resulting in an increased number of seasonal visitors both during and after construction. Large reservoirs in localities which previously were partially arid are themselves focal points of interest and potential vacation areas. In order to accommodate a volume of tourists and vacationists, special facilities are usually provided and operated by the Bureau in cooperation with the National Park Service. The elaborateness of these facilities varies in accordance with the magnitude of the project and the natural scenic beauty created by the impounded waters. PUBLIC FACILITIES

A. Since most of the visitors wish to stop at the dam, ample parking areas are provided close to the structure. Other parking areas are provided at locations commanding views of the dam, canyon, lake, and other points of interest. Care is taken in making the roads and parking areas pleasing in appearance. Parapet walls enclosing the parking areas and lookout points may be constructed of rubble masonry or concrete, depending on their ability to blend with the background or surrounding landscape. PARKING AREAS

B. In order that the visiting public may obtain a better understanding of the technical aspects of the design and construction of the project, guides are usually provided to conduct the visitors through the dam and power house, at the same time pointing out and explaining the salient features of the project. Other conveniences, such as rest houses and drinking fountains, are usually erected in the vicinity of the dam and observation points. As the number of tourists increases, vista houses and concessionary houses may be added. MISCELLANEOUS CONVENIENCES

C. The dam and lake may develop into a recreational center as at Boulder Dam. Cooperative agreements may be made whereby the National Park Service will supervise all recreational developments and activities. Sandy beaches may be constructed at several points along the shore of the lake and provided with facilities RECREATIONAL AREA

(.97C)

for bathing, boating, fishing, aquaplaning, and other water sports. Conducted tours may be made available for an inspection of the lake and to points of interest in surrounding countryside.

STRUCTURAL BEHAVIOR OBSERVATIONS

.98 Although the technique of dam design has progressed through the years, proper satisfaction of the various design criteria as outlined later in this Chapter involves the application of mathematical theories and the effects of physical reactions of strained concrete and foundation materials which, in turn, are based on various assumptions. In order to secure a better understanding of the structural behavior of the concrete mass, and the causes and effects of this behavior, it has been the policy of the Bureau to install various testing devices in dams of relatively major proportions. The testing program includes the study of observed data during the construction period, which is useful in controlling the construction schedule, and continues after construction to observe and study the behavior of the structure as it ages in service.

FEATURES OBSERVED

A. The principal features observed and studied include variation of stress, strain, temperature, creep, growth, crack formation, joint opening, tilting, deflections, and hydrostatic uplift. These features are to a varying degree interdependent, which necessitates adjustments to the observed data in order to study each cause and effect by itself.

TYPES OF INSTRUMENTS

B. The majority of instruments used for determining the behavior of the structure are electrical measuring instruments. These instruments include the elastic-wire strain meter, stress meter, joint meter, crack detector, resistance thermometer, hydrostatic pressure gage, and hydrostatic pressure indicator. They are embedded in the concrete at the time of placing, and heavy rubber insulated cables connect each instrument to control boards located in the gallery. Measurements are taken at the control station with a Wheatstone bridge test set. Non-electric instruments, not embedded in the concrete, include the tiltmeter, plumb line, and theodolite.

FINAL AREA TREATMENT

.99 After the construction of the dam and appurtenant structures, the contractor is required to clean up the general construction area, backfill certain designated areas, and remove and dispose of the excess excavation. Landscaping of the area, depending on the size of permanent operating crew and the number of tourists expected, may be accomplished under separate contract.

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A. Upon completion of the structures, specifications require that the contractor clean up and remove from the vicinity all trash, debris, buildings, unused materials, equipment, concrete forms, and all other like materials used by him or under his direction during the construction period. CLEAN-UP

B. Backfill is placed about the dam, powerplant, spillway apron, or other designated locations to the grades and elevations indicated on the construction drawings. BACKFILL

C. All excess excavation not used for backfill is wasted and deposited in locations designated by the contracting officer. All waste piles and all borrow pits used by the contractor are leveled and trimmed to reasonably regular contours. EXCESS EXCAVATION

D. The amount of landscaping required will depend on the natural features of the terrain, size of permanent operating organization, and the number of tourists expected. Landscaping, planting, walkways and roads may be provided under supplemental contract. LANDSCAPING

METHODS OF STRUCTURAL ANALYSIS

.100 Major developments in the technique of masonry dam design since 1920 have been in the gradual improvement of methods of analyzing stress conditions, with accompanying gradual increase in allowable working stresses. In very high dams, such as Boulder, Grand Coulee, and Shasta, stresses due to dead load alone greatly exceeded the earlier assumptions of maximum allowable pressures. In unusually high masonry dams, shearing stresses may constitute a more important criterion of safety than direct stresses. Vertical, horizontal, and shear stresses at any point within a vertical section of a dam are often required to be known as a basis on which to proportion reinforcement around shafts, galleries, penstocks, and various openings.

GRAVITY ANALYSIS

A. While earlier designers recognized the problem of gravity dams as one of three-dimensional stress, the difficulty in handling such problems with the methods then available resulted in the simplifying assumption that a vertical element of the dam be considered as a two-dimensional stress problem. This is the basis of the gravity method of analysis, wherein it is assumed that each vertical element carries its load to the foundation through the resistance offered by the weight of the element without any transfer of load from or to adjacent vertical elements.

TRIAL-LOAD ANALYSIS

B. Many modifications of this basic assumption have been introduced in an effort to determine as closely as possible the actual state of stress and stability of the structure. The most important of these assumes transfer of forces to take place across transverse horizontal planes by shearing and bending, such that these planes also become subject to two-dimensional solution of forces along them, as in arches and beams. Following this assumption came the logical development of the "trial-load" method of analysis, in which division of the structure into horizontal and vertical two-dimensional elements is succeeded by division of the loads by trial among the systems, such that deflections and other effects are equal at conjugate points.

OTHER MATHEMATICAL METHODS

C. Other two-dimensional methods for analyzing mathematically the stresses in gravity and arch dams involve the determination of nonlinear stress distribution throughout cross-sections of these dams. These methods, most of which are based on certain analogies applied in conjunction with the theory of elasticity, are seldom used for analyzing stresses in cross-sections of other than the highest and most important dams. One of these methods is commonly called the "slab-analysis" and is

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OTHER MATHEMATICAL METHODS (CONT.)

based on an analogy between the stresses in a loaded structure and the curvatures in a two-dimensional slab of like cross-section, loaded at its edges. Another method, recently developed, is based on an analogy between stresses and deformations in a loaded cross-section and the stresses and displacements of a lattice network of diagonally-braced squares approximating the size and shape of the prototype cross-section. This analysis, known as the "lattice analogy," uses relaxation methods for solution.

EXPERIMENTAL METHODS

D. Other analyses, less commonly used in connection with the design of dams, are based on experimental methods using models. These include photoelastic experiments, three-dimensional models using strain gages, experiments involving the use of brittle coatings, and experiments employing various analogies.

FUNCTION OF ANALYSES IN DESIGN

.101 In general, the two methods most commonly used in analyzing the designs of gravity dams are the gravity and trial-load methods, but other more searching methods may be used in borderline cases or final designs of important structures.

USE OF GRAVITY ANALYSIS

A. The gravity method of analysis is almost always used for preliminary design purposes, in varying degrees of completeness, depending upon the information required. This required information usually consists of a knowledge of stability conditions at various cross-sections, vertical stresses normal to and shear stresses parallel to various elevation planes under consideration at the abutments or in the dam, in addition to inclined stresses parallel to the upstream and downstream faces at the edges of the base planes. For final design purposes, this method is almost certain to be the basis for comparison of results with other methods of analysis, trail-load or experimental. By means of the gravity analysis, stability conditions for any given loaded cross-section may be statically determined, or normal, shear, and principal stresses at any point within the section may be computed, based on linear variation of normal stresses across any horizontal plane. Although the gravity method of analysis does not permit exact determination of the theoretical stress and shear at all points, it is sufficient for design purposes of most low- and medium-height dams, up to heights of about 350 feet. In higher dams, slab analyses and other determinations of nonlinear stress distribution by experimental or other means are usually employed for final design purposes.

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B. In preliminary design, the trial-load method of analysis is used for nearly all curved gravity dams, but for straight gravity dams it is applied only to structures of major size and importance. In final design, however, it is used for nearly all curved gravity dams and straight gravity dams located at canyon sites where the side walls are relatively steep or have abrupt changes in side slopes. By this method, it is possible to determine with accuracy the distribution of load between horizontal beam or arch and vertical cantilever elements. The effects of radial shear, tangential shear, and twist on the stresses in curved gravity or arch dams may be analyzed, as well as the effects of shear, twist, and bending on the stability conditions and stresses in straight gravity dams.

USE OF TRIAL-LOAD ANALYSIS

C. When designs of medium-height or high dams are controlled by bearing pressures that are indicated by gravity analyses to approach allowable values, analyses of nonlinear stress distribution are sometimes made. These studies may show stresses considerably in excess of those found from gravity analysis, in some cases sufficiently so to call for a revision of design.

USE OF NONLINEAR STRESS ANALYSES

D. Experimental methods of analysis are seldom used directly for designing dams. However, they are used as a check on other methods of analysis or in designing some particular part of a dam. Local stress concentrations at boundary irregularities, around gallery openings, penstocks, shafts, and other local discontinuities may be studied analytically, if practicable, and checked by measurements on models.

USE OF EXPERIMENTAL STRESS ANALYSES

.102 The analysis of the design of a dam falls into two major operations: the determination of the stability of the structure, and the determination of the stresses within the structure.

GRAVITY ANALYSIS

.103 In the design of straight gravity dams, the stability of any vertical cantilever element of the dam is measured in terms of three safety coefficients of static equilibrium. These three coefficients are known as: the overturning factor of safety; the sliding factor of safety; and the shear-friction factor of safety.

STABILITY FACTORS

A. The factor of safety against overturning is the ratio of the total moment of forces resisting overturning to the total moment of forces tending to cause overturning. The point about which moments are usually

OVERTURNING FACTOR

(.103A)

considered is at the downstream edge of the base of the section under consideration. Thus, a factor of safety of 1.0 would indicate a section to be just on the verge of overturning. In practice, a factor of safety above 1.5, including earthquake effects, is generally sought. Transverse sections of a dam derive an additional measure of resistance against overturning from adjacent more stable sections through resistance to shearing at the interface.

SLIDING FACTOR

B. The sliding factor is one of the oldest criteria for the design of gravity dams. It is represented as a coefficient of frictional resistance and is the ratio of the total forces tending to slide a vertical section downstream to the total normal forces tending to stabilize it by gravity action, less the effect of uplift. The active shearing forces directed downstream includes the horizontal component of the reservoir water force plus the hydrodynamic and inertia forces resulting from earthquake shocks, minus the restraining forces exerted by tailwater loads. Other restraining forces, passive in nature, such as resistances offered at the downstream toe by buckets or aprons, by powerhouse structures, or by partial embedment in the foundation, are not usually considered in the total because of the uncertainty of their contribution to the total effect. It is essential to provide the dam with sufficient weight to overcome its tendency to slide. The usual procedure is to design for a sliding factor value between 0.60 and 0.80 for normal loading conditions, depending on the quality of the foundation. Encroachments on the allowable values of sliding factor up to 1.0 are sometimes permitted for temporary, abnormal loading conditions, such as earthquake shock.

SHEAR-FRICTION FACTOR

C. A masonry dam generally has an intangible but important element of strength due to cohesion of its parts, if constructed monolithically, and due to adhesion between the foundation rock and the masonry, if care is taken to bound the masonry to the rock at the start of the construction. This is an added security against failure by sliding, as it first involves the necessity of shearing of the monolith along a joint. Evaluation of the contribution of shearing resistance to sliding within the structure itself, between the structure and the foundation, or in foundation planes immediately below the base of the structure, is made by Henny's shear-friction factor of safety which has been adopted by the Bureau as one of the most important criteria

(.103C)

SHEAR-FRICTION FACTOR (CONT.)

for designing gravity-type dams. The shear-friction factor of safety is the ratio of the total shearing resistance to the total downstream force tending to cause movement in that direction. The total shearing resistance on any horizontal or inclined plane is the product of the base area of the vertical element at that plane times a conservative value of the average shear strength of the materials under consideration, plus the additional shear strength due to the forces normal to the plane considered, the latter simply being the resultant weight force, minus uplift, times a conservative estimate of the coefficient of friction. Expressed mathematically, the shear-friction factor of safety at a horizontal plane of a vertical element may be calculated by the formula, $Q = \frac{\Sigma(W+U)f + As}{\Sigma V}$, where

Q is the shear-friction factor of safety; W, the resultant weight force; U, the uplift force; f, a conservative estimate of the coefficient of friction which has been established as 0.65 in the Bureau; A, the base area of the section under consideration; s, the average value of unit shearing strength at the plane being considered; and ΣV, the total horizontal force tending to cause movement in a downstream direction. A minimum shear-friction factor of safety of 5.0 has been set as a design value by the Bureau for the case of normal reservoir operating conditions plus the most severe effects of horizontal and vertical earthquake accelerations of 0.1 g. This is easily satisfied for all dams but those of exceptional height or dams founded on poor foundations. Factors of safety against failure by shear along vertical planes may be calculated by methods similar to those used in computing shear-friction factors of safety. In these computations, however, the safety factors do not include weight effect, and depend only on total shearing forces and total shearing strengths along vertical planes.

GRAVITY STRESS ANALYSIS

.104 Most straight gravity dams built in the past, even in cases where maximum heights exceeded 300 feet, have been designed entirely on the basis of gravity action. Usually the cross-sections have been so proportioned that the resultant of the horizontal and vertical forces fell within the middle-third area of any horizontal base plane, to avoid tensile direct stresses at the upstream edge of the base. In some cases, Levy's criterion has governed the designs: that the concrete stresses at all elevations

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GRAVITY STRESS ANALYSIS (CONT.)

of the upstream face should be compressive and not less than the reservoir water pressure. Maximum allowable stresses depend on character and quality of the rock foundation as well as on strength of the concrete. Under the most favorable foundation conditions, sections of gravity dams are usually determined so that the maximum direct stresses by gravity analysis will not exceed 650 psi and maximum shear stresses will not exceed 600 psi. In addition to maximum stresses, vertical, horizontal, and shear stresses are required in the interior of the dam for proportioning reinforcement around openings. Formulas for calculating these stress conditions, assuming a trapezoidal distribution of vertical stress and a parabolic distribution of shear stress, have been derived by calculus without approximation, and present a direct method of statically determining stresses at any point within the boundaries of a transverse section of a gravity dam. The assumptions of linear distribution of vertical stresses and parabolic distribution of shear are substantially correct for horizontal planes of cantilever elements except those approaching the base. The following method is therefore adequate for ordinary design purposes for straight gravity dams, except those of unusual height.

ASSUMPTIONS

.105 The assumptions used in the development of the equations for calculating internal stress conditions are as follows:

A. All loads are resisted by the gravity action of a vertical cantilever element having parallel sides one foot apart.

B. The unit vertical pressures or normal stresses on horizontal planes are assumed to vary linearly from the upstream face to the downstream face of the dam.

C. Horizontal shear stresses are assumed to have a parabolic variation across horizontal planes from the upstream face to the downstream face of the dam.

D. The unit cantilever element is assumed to be in static equilibrium on a rigid foundation.

E. Stress changes which take place in a dam subjected to an earthquake shock are due to:

(1) The accelerations of the mass of the dam in horizontal and vertical directions.

(.105E)

(2) The changes in water pressures acting on the faces of the dam.

ASSUMPTIONS (CONT.)

F. The horizontal accelerations due to a horizontal earthquake shock are assumed to act in an upstream or downstream direction normal to the axis of the dam.

G. By the principle of D'Alembert, the dynamic action of the mass of the dam may be transformed into a problem of statics by including in the equations the horizontal inertia force expressed as mass times acceleration reversed.

H. The fundamental theory used for determining changes in water pressures during horizontal earthquake shocks is based on Westergaard's equation:

$P_E = C\lambda\sqrt{Zh}$, as defined in the nomenclature.

I. A vertical earthquake shock is assumed to produce an acceleration of the mass of the dam and water in the opposite direction to that of the shock. The acceleration generally assumed is one-tenth that due to gravity, acting for a period of one second.

J. The equations presented in the subsequent paragraphs were developed for computing stresses in the dam for normal loading conditions, or normal conditions plus the effect of a horizontal earthquake shock. Effects of a vertical earthquake shock may be properly included in the computations for total vertical forces and moments that enter into the equations.

K. Uplift effects are usually omitted in calculations for stresses, but are included in computations of stability factors.

NOMENCLATURE

.106 In the following definition of terms, the word "section" refers to a horizontal plane through the unit cantilever element.

Referring to Figure 29:

(') Indicates symbol for tailwater

Subscripts:

E = earthquake

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NOMENCLATURE (CONT.)

U = upstream face
D = downstream face

O = origin of coordinates, at downstream edge of section

ϕ = vertical angle of face

T = horizontal distance between faces

c = horizontal distance from the center of gravity to either face = $\frac{T}{2}$

A = area of section = T x 1

I = moment of inertia of section about center of gravity = $\frac{T^3}{12}$

ω_c = unit weight of concrete

ω = unit weight of water

h = vertical distance from water surface to section under consideration

Z = height of water surface above base of maximum cantilever

p = water pressure at section due to normal loading conditions = ωh

p_E = change in water pressure at section due to a horizontal earthquake shock = $C\lambda\sqrt{Zh}$

C = a constant depending upon the ratio of Z to period of horizontal vibration of foundation

$$C = \frac{51}{\sqrt{1 - 0.72\left(\frac{Z}{1000\ N}\right)^2}} \text{ pounds per cubic foot}$$

N = period of horizontal vibration of foundation, generally assumed as one second. With this assumption, C varies from 51 to 63 lb/cu. ft. for dams up to 700 feet in height

λ = $\frac{\text{maximum horizontal acceleration of foundation}}{\text{acceleration due to gravity}}$, generally assumed as one-tenth

(.106)

NOMENCLATURE (CONT.)

W = weight of concrete above section

M = moment of W about center of gravity of section

W_ω = vertical component of water load on face above section, for normal loading conditions

M_ω = moment of W_ω about center of gravity of section

$W_{\omega E}$ = change in vertical component of water load on face above section due to a horizontal earthquake shock

$M_{\omega E}$ = moment of $W_{\omega E}$ about center of gravity of section

V = horizontal component of water load on face above section $= \frac{\omega h^2}{2}$ for normal conditions

M_p = moment of V about center of gravity of section $= \frac{\omega h^3}{6}$

V_{pE} = change in horizontal component of water load on face above section due to a horizontal earthquake shock

M_{pE} = moment of V_{pE} about center of gravity of section

V_E = horizontal inertia force of dead load above section $= W\lambda$

M_E = moment of V_E about center of gravity of section

ΣW = resultant vertical force above section
$= W + W_\omega + W'_\omega \pm W_{\omega E} \pm W'_{\omega E}$

ΣV = resultant horizontal force above section
$= V + V' \pm V_E \pm V_{pE} \pm V'_{pE}$

ΣM = resultant moment of forces above horizontal section about center of gravity

$= M + M_\omega + M'_\omega + M_p + M'_p \pm M_E \pm M_{\omega E} \pm M'_{\omega E} \pm M_{pE} \pm M'_{pE}$

σ_z = normal stress on horizontal plane

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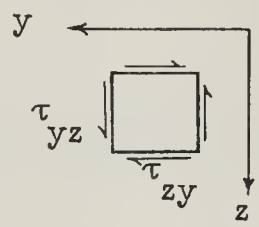
NOMENCLATURE (CONT.)

σ_y = normal stress on vertical plane

$\tau_{zy} = \tau_{yz}$ = shear stress on a vertical or horizontal plane. Positive shear stresses are as shown:



a, a_1, a_2, b, b_1, b_2, c_1, c_2, d_2 = constants

σ_{p_1} = first principal stress

σ_{p_2} = second principal stress

ϕ_{p_1} = angle between σ_{p_1} and the vertical, positive clockwise

Positive horizontal forces act in the upstream direction.

Positive moments produce compression at the upstream face of the cantilever.

The algebraic signs of the terms containing the subscript E in the equation for ΣW, ΣV, and ΣM depend upon the direction assumed for the horizontal earthquake acceleration of the foundation.

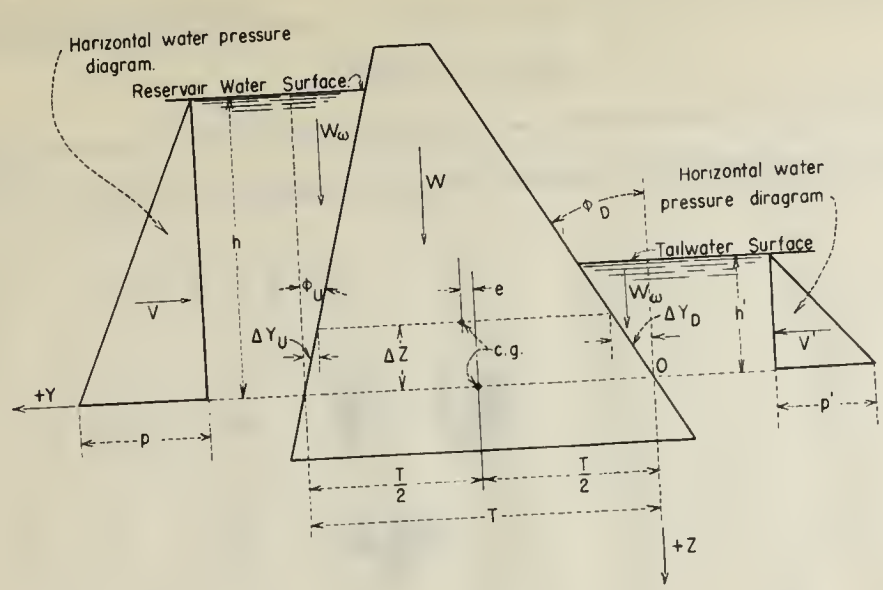
Compression is positive.

SUMMARY OF EQUATIONS

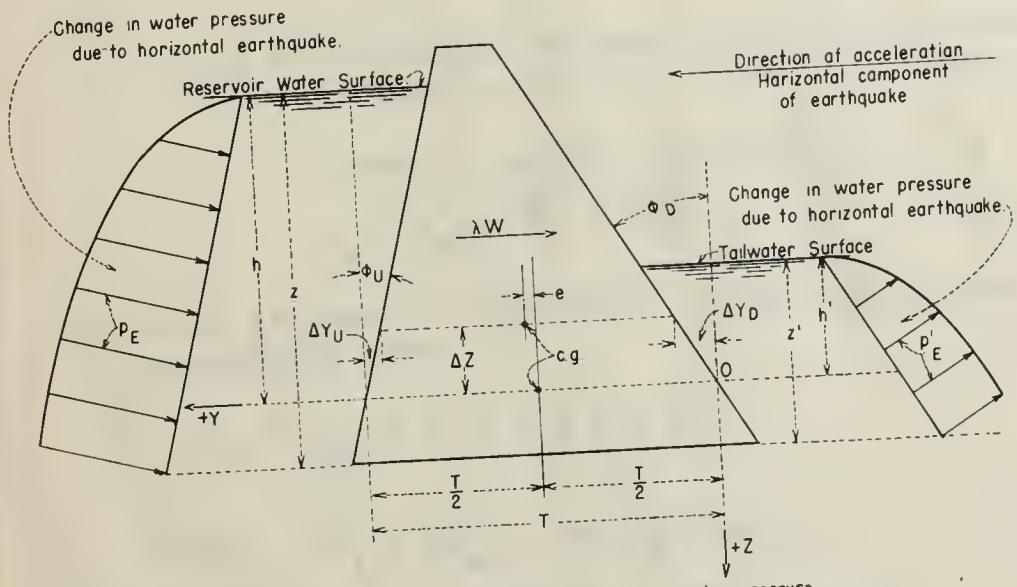
.107 Equations for gravity stress analysis are given below in four groups, for analyzing: normal stresses on horizontal planes; shear stresses; normal stresses on vertical planes; and principal stresses and their directions at any point within the boundaries of a vertical cantilever element.

In the equations, terms that are due to earthquake are preceded by the algebraic sign plus or minus. As these occur, the correct sign to be applied to each term for the upstream direction of earthquake shock will be indicated by the upper algebraic symbol.

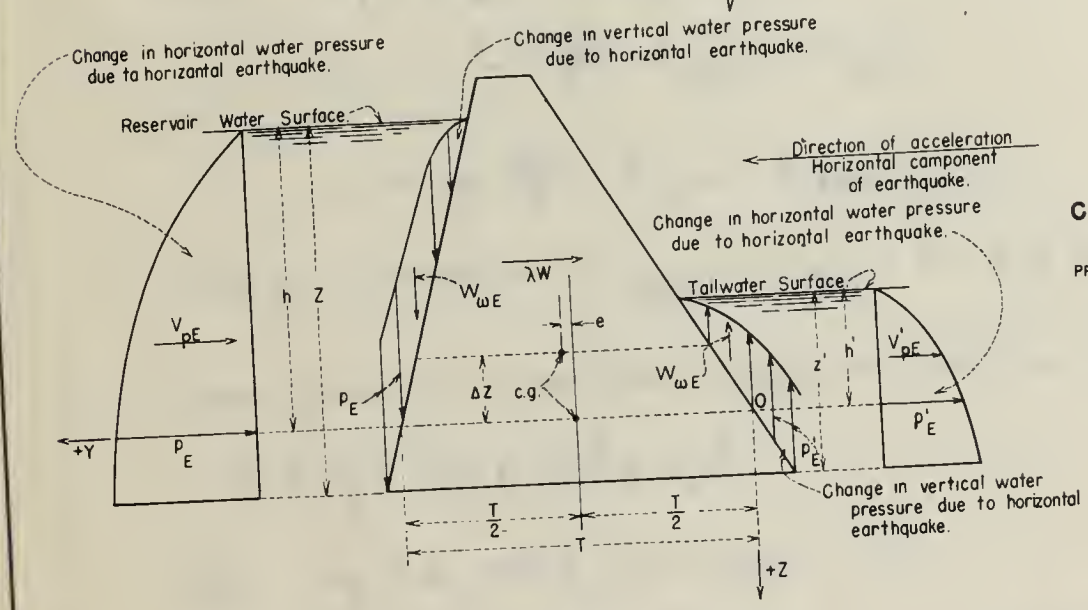
FIG. 29 par. 5.2.106



NORMAL LOADING CONDITIONS

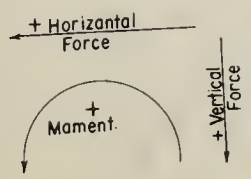


EARTHQUAKE LOADING CONDITIONS



CHANGES IN LOADING CONDITIONS

PRESSURE DIAGRAMS SHOWING CHANGES IN HORIZONTAL AND VERTICAL COMPONENTS OF WATER LOADS DUE TO HORIZONTAL COMPONENT OF EARTHQUAKE ACTING IN UPSTREAM DIRECTION.



DIRECTION OF POSTIVE FORCES AND MOMENTS

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

GRAVITY ANALYSIS

NORMAL AND EARTHQUAKE LOADS

BY	W.A.T.	JUNE 25, 1946
APV.	C.R.	MD-DT-9

(.107)

A. Normal stresses on horizontal planes are found by

NORMAL STRESSES ON HORIZONTAL PLANES.

$$\sigma_z = a + by$$

where $a = \frac{\Sigma W}{T} - \frac{6\ \Sigma M}{T^2}$

$b = \frac{12\ \Sigma M}{T^3}$

y = horizontal distance from origin at downstream face to point under consideration.

Check at upstream face where $y = T$,

$$\sigma_z = \sigma_{zU} = \frac{\Sigma W}{T} + \frac{6\Sigma M}{T^2}$$

B. Shear stresses on horizontal or vertical planes may be computed from

SHEAR STRESSES

$$\tau_{zy} = \tau_{yz} = a_1 + b_1 y + c_1 y^2$$

where $a_1 = (\sigma_{zD} - p' \pm p'_E) \tan \phi_D$

$$b_1 = -\frac{1}{T}\left(\frac{6\Sigma V}{T} + 2\tau_{zyU} + 4\tau_{zyD}\right)$$

$$c_1 = \frac{1}{T^2}\left(\frac{6\Sigma V}{T} + 3\tau_{zyU} + 3\tau_{zyD}\right)$$

Check at upstream face: $\tau_{zyU} = -(\sigma_{zU} - p \pm p_E) \tan \phi_U$

C. Normal stresses on vertical planes are found by

NORMAL STRESSES ON VERTICAL PLANES

$$\sigma_y = a_2 + b_2 y + c_2 y^2 + d_2 y^3$$

where $a_2 = a_1 \tan \phi_D + p' \pm p'_E$

$$b_2 = b_1 \tan \phi_D + \frac{\partial a_1}{\partial z} \mp \lambda \omega_c$$

$$c_2 = c_1 \tan \phi_D + \frac{1}{2}\frac{\partial b_1}{\partial z}$$

$$d_2 = \frac{1}{3}\frac{\partial c_1}{\partial z}$$

(.107C)

NORMAL STRESSES ON VERTICAL PLANES (CONT.)

Check at upstream face: $\sigma_{yU} = (p \pm p_E - \tau_{zyU} \tan \phi_U)$

The partial derivatives forming the above terms are evaluated by the equations which follow. Partial derivatives defined by equations involving the difference of identical terms are evaluated by applying the function to points a finite distance Δz apart.

$$\frac{\partial a_1}{\partial z} = \frac{\partial \tau_{zyD}}{\partial z} = \tan \phi_D \left(\frac{\partial \sigma_{zD}}{\partial z} \pm \frac{\partial p'_E}{\partial z} - \omega\right)$$

$$+ \frac{\partial \tan \phi_D}{\partial z} (\sigma_{zD} - p' \pm p'_E)$$

(Omit ω if tailwater is absent.)

$$\frac{\partial \sigma_{zD}}{\partial z} = \omega_c + \tan \phi_U \left(\frac{12\Sigma M}{T^3} + \frac{2\Sigma W}{T^2} - \frac{2p}{T} \mp \frac{2p_E}{T}\right)$$

$$+ \tan \phi_D \left(\frac{12\Sigma M}{T^3} - \frac{4\Sigma W}{T^2} + \frac{4p'}{T} \mp \frac{4p'_E}{T}\right) - \frac{6\Sigma V}{T^2}$$

$$\frac{\partial p'_E}{\partial z} = \frac{(p'_E - p'_E)}{\Delta z}$$

$$\frac{\partial \tan \phi_D}{\partial z} = \frac{(\tan \phi_D - \tan \phi_D)}{\Delta z}$$

If no change in slope occurs in the Δz distance

$$\frac{\partial \tan \phi_D}{\partial z} = 0$$

$$\frac{\partial b_1}{\partial z} = -\frac{1}{T^2}\left[\frac{6\partial \Sigma V}{\partial z} - \frac{\partial T}{\partial z}\left(\frac{12\Sigma V}{T} + 2\tau_{zyU} + 4\tau_{zyD}\right)\right]$$

$$- \frac{1}{T}\left[2\left(\frac{\partial \tau_{zyU}}{\partial z}\right) + 4\left(\frac{\partial \tau_{zyD}}{\partial z}\right)\right]$$

(.107C)

$$\frac{\partial \Sigma V}{\partial z} = -\left(p - p' \pm \lambda \omega_c T \pm p_E \pm p'_E\right)$$

NORMAL STRESSES ON VERTICAL PLANES (CONT.)

$$\frac{\partial T}{\partial z} = \tan\phi_U + \tan\phi_D$$

$$\frac{\partial \tau_{zyU}}{\partial z} = \tan\phi_U \left(\omega - \frac{\partial \sigma_{zU}}{\partial z} \pm \frac{\partial p_E}{\partial z}\right) + \frac{\partial \tan\phi_U}{\partial z}\left(p \pm p_E - \sigma_{zU}\right)$$

(Omit ω if reservoir water is absent)

$$\frac{\partial \sigma_{zU}}{\partial z} = \omega_c + \tan\phi_U \left(\frac{4p}{T} \pm \frac{4p_E}{T} - \frac{4\Sigma W}{T^2} - \frac{12\Sigma M}{T^3}\right)$$
$$+ \tan\phi_D \left(\frac{2\Sigma W}{T^2} \pm \frac{2p'_E}{T} - \frac{2p'}{T} - \frac{12\Sigma M}{T^3}\right) + \frac{6\Sigma V}{T^2}$$

$$\frac{\partial p_E}{\partial z} = \frac{(p_E - p_E)}{\Delta z}$$

$$\frac{\partial \tan\phi_U}{\partial z} = \frac{(\tan\phi_U - \tan\phi_U)}{\Delta z}$$

If no change in slope occurs in the Δz distance

$$\frac{\partial \tan\phi_U}{\partial z} = 0$$

$$\frac{\partial c_1}{\partial z} = \frac{1}{T^3}\left[\frac{6\partial \Sigma V}{\partial z} - \frac{\partial T}{\partial z}\left(\frac{18\Sigma V}{T} + 6\tau_{zyU} + 6\tau_{zyD}\right)\right]$$
$$+ \frac{1}{T^2}\left[3\frac{(\partial \tau_{zyU})}{\partial z} + 3\frac{(\partial \tau_{zyD})}{\partial z}\right]$$

Effects of earthquake shock on stresses may be excluded by omitting the terms preceded by the alternate plus or minus ($\pm$) signs from the above equations. The equations then reduce to the proper forms for computing stresses for normal loading conditions.

D. After the stresses σ_z, σ_y, and τ_{zy} have been computed at any point within the cantilever

PRINCIPAL STRESSES

(.107D)

PRINCIPAL STRESSES (CONT.)

cross-section by the foregoing formulas, the magnitude and directions of principal stresses at the point may be computed from the following equations:

$$\sigma_{p_{1,2}} = \frac{(\sigma_z + \sigma_y)}{2} \pm \sqrt{\frac{(\sigma_z - \sigma_y)^2}{2} 2 + (\tau_{zy})^2}$$

If $(\sigma_z - \sigma_y) > 0$, use + sign to obtain σ_{p_1}

If $(\sigma_z - \sigma_y) < 0$, use - sign to obtain σ_{p_1}

The angle that the first principal stress, σ_{p_1} makes with the vertical is given by

$$\phi_{p_1} = \frac{1}{2} \text{ arc tan} \left[- \frac{\tau_{zy}}{\frac{(\sigma_z - \sigma_y)}{2}} \right]$$

If tan $2\phi_{p_1}$ is +, $0^\circ < \phi_{p_1} < (+45^\circ)$ measured from vertical.

If tan $2\phi_{p_1}$ is -, $(-45^\circ) < \phi_{p_1} < 0^\circ$, measured from vertical. Clockwise angles are positive.

TRIAL-LOAD ANALYSIS

.108 A description of the trial-load method of analysis is given in Chapter 5.3 under the heading "Trial-load Method of Analyzing Arch Dams." The trial-load method may be used in analyzing any solid masonry dam, whether it be arch or gravity. In the case of a straight gravity dam, an assumed structural system cannot transfer loads horizontally to the abutments by arch action, but a structural system can be conceived that provides for a logical transfer of load by direct shear and twist. Such a system is called the twisted structure system. Consequently, the trial-load method of analyzing a straight gravity dam consists of assuming different distributions of load between cantilever and twisted structure elements and calculating corresponding cantilever and twisted

(.108)
structure deflections until these movements agree at conjugate points.

TWIST ACTION

.109 Such analyses, as have been made thus far, of twist conditions in straight gravity dams show that appreciable portions of load are transferred laterally to the abutments by twist action in the end sections of the structures, where the vertical cross-sections are of gradually or abruptly decreasing heights. The existence of twist action may be seen by considering the gravity dam to be made up of a series of vertical cantilever elements perpendicular to the axis of the dam. In an ordinary damsite, most of the cantilever elements will be of unequal height. The high central cantilevers tend to deflect downstream farther than the lower abutment cantilevers due to their greater height and greater total load at the upstream face. Hence, going from the central portion toward the abutments, each succeeding cantilever will be deflected less than the preceding one and more than the succeeding one. However, since each element is an integral part of the dam and not free to move independently of the others, the intervening cantilever must be affected by the adjacent ones. This interaction between cantilever elements causes torsional moments, or twists, which result in the lateral transfer of some portions of the external loads to the abutment rock by twist action.

A. The maximum effects of twist action in seven gravity dams are shown in Figure 30.

SUMMARY OF TWIST EFFECTS

The most noteworthy effects of twist action on stresses and stability factors obtained by trial-load studies, as compared with those quantities obtained by gravity analysis, may be briefly summarized as follows:

(1) An increase in sliding factors along the steeper inclined rock planes which form the bases of the cantilevers in the abutment sections.

(2) A decrease in sliding factors in the longer cantilevers whose bases are located in the lower regions of the abutment slopes.

(3) A decrease in shear-friction factor of safety along the steeper inclined rock planes at the abutment cantilevers.

(.109A)

SUMMARY OF TWIST EFFECTS (CONT.)

(4) An increase in shear-friction factor of safety at the high cantilevers near the lower ends of the abutment slopes.

(5) Relatively small changes in stresses and stability factors in the longer cantilevers near the central section of the dam where most of the external load is carried by the cantilevers.

(6) A decrease in inclined cantilever compressive stresses along the base of the dam at the downstream edges of the abutment sections and as far toward the center of the structure as appreciable portions of external load may be carried by twist action.

(7) An increase in inclined cantilever compressive stresses along the base of the dam at the upstream edges of the abutment sections and as far toward the center of the structure appreciable portions of external load may be carried by twist action.

(8) The development of appreciable horizontal compressive stresses at and parallel to the downstream face, decreasing in magnitude from the abutment slopes toward the center of the dam.

(9) The development of appreciable horizontal tensile stresses at and parallel to the upstream face of the dam, with possible resulting cracking, decreasing in magnitude and effect from the abutment slopes toward the center of the dam.

(10) Wherever the deflection curves of the horizontal elements may indicate the possible existence of relatively high tensile stresses, diagonal cracking may occur. This condition may exist especially near the points of contraflexure of horizontal elements in the upper portions of the dam.

BENEFICIAL VS. DETRIMENTAL EFFECTS

B. It is seen from the above summary that both beneficial and detrimental effects on loads, stresses, and stability factors for straight gravity dams may accrue by twist action. The lateral transfer of load to the abutments causes some reduction in load on the high cantilevers at the lower ends of the abutment slopes. However, the beneficial results of such reductions are usually of minor importance in comparison with the detrimental effects of load increases on the

TABLE I

MAXIMUM EFFECTS OF TWIST ACTION IN SOME GRAVITY DAMS, WITH PRINCIPAL DIMENSIONS OF TWISTED STRUCTURE

GENERAL DIMENSIONS AND DATA

ITEM		NAME OF DAM						
		Madden	Norris	O'Shaughnessy	Grand Coulee	Friant	Marshall Ford	Davis
Location		Panama Canal Zone	Tennessee	California	Washington	California	Texas	Ariz.-Nevada
River		Chagres	Clinch	Tuolumme	Columbia	San Joaquin	Lower-Colo.	Lower-Colo.
Maximum height of twisted section		210	260	382	458	267	268	153
Length of twisted section		950	1580	850	4118	3390	2700	402
Width at top of dam		22	20	27.5	30	20	30	32
Width at base of maximum section		176	210	308	394	220	216	110
Upstream projection at base		12	15	16	26	17	11	0
Downstream projection at base		144	175	264	338	183	175	78
Loading condition analyzed		Full Reservoir	Full Reservoir	Full Reservoir +Earthquake	Full Reservoir +Earthquake	Full Reservoir +Earthquake	Full Reservoir +Earthquake	Full Reservoir +Earthquake
SLIDING FACTORS	Maximum increase at any position	0.40-0.75	0.44-0.69	0.43-1.49	0.35-0.48	0.80-0.84	0.73-0.74	
					0.42-1.19	0.84-0.93	0.39-0.68	0.07-3.84
	Maximum decrease at any position	0.90-0.62	0.64-0.37	0.87-0.46	0.79-0.41	0.88-0.82	0.66-0.48	
					0.79-0.55	0.88-0.79	0.66-0.49	0.50-0.29
SHEAR-FRICTION FACTOR	Maximum increase at any position			22.7-37.4	32.4-54.2	5.9-6.3	31.0-34.1	
					24.3-31.5	7.2-7.9	5.9-8.0	30.1-77.6
	Maximum decrease at any position			37.7-10.9	17.4-12.8	18.3-17.8	12.7-12.5	
					76.5-52.0	10.5-9.2	92.1-72.9	129.4-8.7
CANTILEVER STRESSES COMPRESSION	Maximum increase at upstream face	66-94	81-123	1-126	126-217	31-37	98-124	
				1-228	130-278	22-53	101-161	-11-140
	Maximum decrease at downstream face	198-156	224-163	508-279	511-366	382-374	220-180	
				508-93	520-282	318-274	286-197	292-75
Remarks:				Designed as Gravity Dam Radius 700 ft				Concrete Gravity Penstock Section

Notes:

Figures above line-Joints ungrouted. Figures below line-Joints grouted.

Dimensions in feet, Stresses in p.s.i., Stresses act parallel to face.

FIG. 30 par. 5.2.109

(.109B)

shorter end cantilevers. In some cases, sliding factors at the bases of these shorter cantilevers are increased to more than unity; so that the sections theoretically would move downstream if they were not held in place by the shear resistance and weight of the mass of the dam. Fortunately, shear-friction factors of safety at the bases of gravity sections increase as the heights of the sections decrease. Consequently, the shear resistance at the bases of the end cantilevers is usually great enough to prevent failure.

BENEFICIAL VS. DETRIMENTAL EFFECTS (CONT.)

C. Theoretically, it may sometimes be possible to save concrete by reducing slightly the thickness of the cross-section at regions where twist action is indicated to be beneficial. In practice, however, it is usually desirable to keep the slopes of the faces constant throughout the length of the dam for economy of construction. Another reason for not making reductions in cross-section to allow for the effects of beneficial twist action is that allowances for non-linear distribution of stress throughout the sections would probably overshadow the beneficial effects of twist action.

REDUCTION IN CROSS-SECTION

.110 The general theory of twist action is an improvement and modification of the gravity theory of design where the dam is assumed to be made up of a series of unit cantilever elements, each of which transfers its load directly to the foundation by gravity action without any transfer of forces to or from adjacent elements. In the theory of twist action, part of the total loads carried by an element of the dam is assumed to be transferred to adjacent vertical elements across a transverse structural system. The determination of forces thus transferred along any horizontal two-dimensional plane lying within that system may then be accomplished. To accommodate this theory, the body of the dam is considered to consist of two structural systems, the cantilever structure system and the twisted structure system, each identical with the dam, and both occupying the same space at the same time. However, each system of structures is limited to the types of resistance explained below, and illustrated in Figure 31.

GENERAL THEORY OF TWIST ACTION

A. The cantilever structure system is composed of a series of abutting vertical cantilever elements. It transfers the dead load and a portion of the total external loads to the foundation by gravity action. The elements act in the same way as the cantilevers

CANTILEVER STRUCTURE SYSTEM

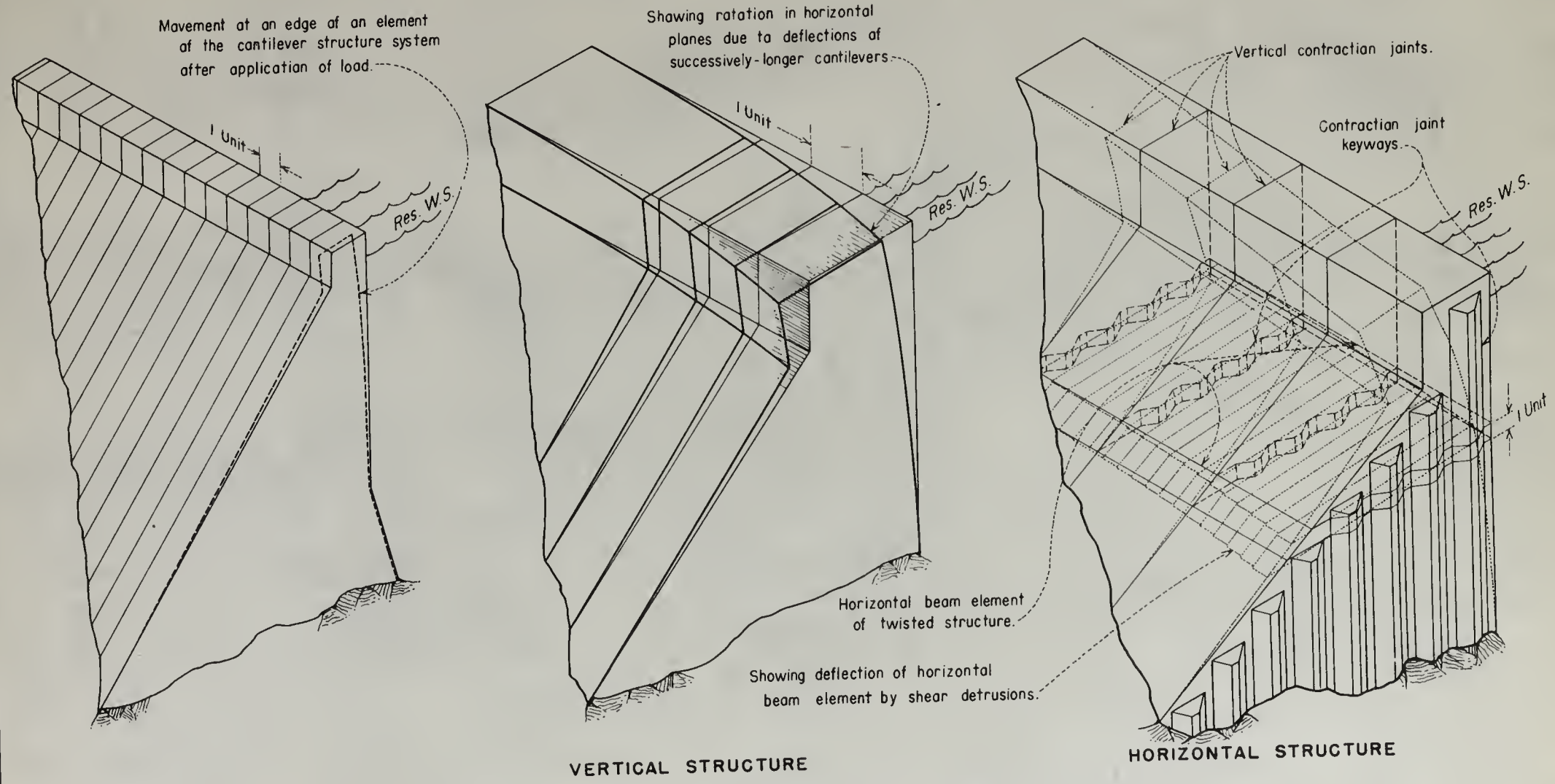
(.110A)

CANTILEVER STRUCTURE SYSTEM (CONT.)

in an arch dam; that is, they carry external load downward to the foundation by bending and shear along horizontal planes without being restrained by the elements of the twisted structure, just as the cantilever elements in an arch dam transfer loads downward without being restrained by the arch elements. The cantilever structure system is capable of two types of structural deformation, bending caused by flexure and detrusions caused by shear in each cantilever unit.

TWISTED STRUCTURE SYSTEM

B. The twisted structure system is made up of vertical sections or blocks, keyed together by vertical keyways in the contraction joints. If the joints are not grouted, the system is considered capable, by virtue of the keyways at the joints, of transmitting load horizontally to the abutments by torsion in horizontal planes and by transverse shear in vertical transverse planes. If the contraction joints are grouted, the system is considered capable of transmitting load downward to the foundation by torsion in vertical planes as well as horizontally to the abutments by twist and shear. In the latter case, the dam is also considered capable of transmitting some load horizontally to the abutments by flexure, and this transmittal is computed separately. The twisted structure system is considered to be replaced by two structural systems, one vertical and the other horizontal. The vertical structure is composed of a system of abutting vertical unit cantilever elements. It offers structural resistance by torsion in horizontal planes of cantilevers. Under load, it deforms by rotation in horizontal planes due to increasingly greater downstream deflection of successively longer cantilevers. The summed rotations become transverse shear deflections of the composite cantilever structure. The horizontal structure is a system of segmented horizontal beam elements spanning from abutment to abutment. Its structural resistance is by torsion in horizontal planes only, if the contraction joints are not grouted, or by torsion in both horizontal and transverse vertical planes if the contraction joints are grouted. If flexural action of horizontal beam elements is considered, it has been found expedient to consider this effect separately and divide the external load by trial between the cantilever structure system, twisted structure system, and a separate flexural system of horizontal beams. The type of structural movement of the horizontal system depends on whether or not the joints are grouted. Ungrouted joints permit deflection in horizontal planes



THE CANTILEVER STRUCTURE SYSTEM

THE TWISTED STRUCTURE SYSTEM

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

TRIAL LOAD TWIST ANALYSIS

CANTILEVER AND TWISTED STRUCTURE SYSTEMS

BY	W.A.T.	JUNE 27, 1946
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FIG. 31 par. 5.2.110

(.110B)

by shear detrusions only. With the joints grouted, beam elements can deflect and rotate in horizontal planes, and can rotate in transverse vertical planes. The portion of the load transmitted horizontally to the abutments by flexure, if considered, is computed separately from that portion transferred by shear detrusions. As to the structural resistance of the composite structure, when the joints are not grouted, torsion cannot be transmitted in vertical planes across keyways. With the joints grouted, the structure acts as a monolith and flexure in horizontal beams is assumed only for the special case described above. The total deflections of the twisted structure equals the sum of the deflections of the vertical and horizontal structural systems.

TWISTED STRUCTURE SYSTEM (CONT.)

C. The criterion which determines the distribution of total load between the separate systems is that the deflections of the separate systems of load transfer must coincide at conjugate points, in the same manner as in a trial-load analysis of an arch dam.

COINCIDENCE OF DEFLECTIONS OF THE TWO SYSTEMS

D. As stated above, the dead load of the structure is assumed to be carried wholly by the cantilever structure system. The deflections due to dead load are assumed to take place gradually during the construction of the dam, prior to the grouting of the contraction joints, without any lateral transfer to adjacent cantilever elements by vertical arching. The vertical components of water load are also assumed carried by the cantilever elements. This is handled in the analysis by measuring the downstream deflections of the cantilevers, due to their portions of the horizontal external loads, from the initially-deflected upstream positions of the cantilevers due to the vertical water loads. The downstream deflections of the twisted structure system are measured only from the original positions of the vertical elements before the application of vertical water loads. After satisfactory deflection agreement between the separate structural systems at conjugate points has been reached, the effects of vertical water loads and dead loads are included with the calculations for cantilever stresses.

DEAD LOAD AND WATER LOAD

.111 The transverse contraction joints, Figure 31, divide the dam into a segmented series of vertical blocks separated from each other during construction by standard vertical keyways. Often these keyways are left ungrouted during

TRIAL-LOAD TWIST ANALYSIS, UNGROUTED JOINTS

(.111)

TRIAL-LOAD TWIST ANALYSIS, UNGROUTED JOINTS (CONT.)

construction, during which time the joints can have no appreciable resistance to bending in either horizontal or vertical planes. The joints, however, through the action of the keyways, can transfer shears laterally to the abutments, but are incapable of transferring shears vertically to the foundation at this stage. The method of making a trail-load twist analysis for a straight gravity dam with ungrouted joints will be presented from the viewpoints of assumptions, nomenclature, and procedure.

ASSUMPTIONS .112 It is assumed that:

A. The dam is replaced by the two structural systems, the vertical cantilevers and the twisted structure, which are described in Paragraph 5.2.110.

B. The contraction joints of the dam are not to be grouted and the dam acts as a series of keyed vertical elastic blocks, set on elastic bases.

C. The contraction joints can transfer shears horizontally, but not vertically.

D. The cantilevers can twist in horizontal planes, but the horizontal beams cannot twist in vertical planes.

E. The cantilevers are subject to bending in vertical planes, but bending action in horizontal beams is prevented by the open joints.

F. The twisted structure resists torsions in the horizontal planes only.

NOMENCLATURE .113 For this analysis, the following nomenclature and units will apply:

x, y, z = coordinates . . . . . ft

M_x = bending moment in plane parallel to yz-plane . . . . . ft-lb

M_z = bending moment in plane parallel to xy-plane . . . . . ft-lb

M_{xy} = twisting moment in horizontal xy-plane . . . . . ft-lb

M_{yz} = twisting moment in vertical zy-plane . . . . . ft-lb

(.113)

NOMENCLATURE (CONT.)

V = total horizontal thrust of external load . . . . . lb

V_c = shear in cantilever due to horizontal component of external load carried by cantilever . . . . . lb

V_t = shear in horizontal element of twisted structure due to horizontal component of external load carried by twisted structure . . . . . lb

Subscript A in ${}_AM_{xy}$, ${}_AV_c$, etc., indicates twisting moment at abutment in xy-plane, and shear at base of cantilever, respectively.

T = thickness of dam at a given elevation ft

E_c = modulus of elasticity of concrete in tension or compression . . . . . lb per ft^2

E_r = modulus of elasticity of abutment material in tension or compression . . lb per ft^2

G = modulus of elasticity of concrete in shear . . . . . lb per ft^2

μ = Poisson's ratio

θ_z = angular rotation in horizontal plane radians

Δy = deflection normal to axis . . . . . ft

Z = vertical distance from base of cantilever . . . . . ft

I = moment of inertia of each unit width or height of cross-section . . . . . ft^4

J = a factor used in computing angular rotations of cantilevers due to torsions, in the case of joints not grouted.

p = external pressure at any depth h . . . lb per ft^2

A = area of cross-section of a cantilever or beam element . . . . . ft^2

L = length of a horizontal beam element ft

P = unit load ordinate . . . . . lb

(.113)

NOMENCLATURE (CONT.)

K = a constant which depends upon the ratio of the actual shear distribution across a section to a uniform shear distribution.

In these analyses $K = 1.25$ and $\frac{K}{G} = \frac{3}{E}$

ψ = angle between canyon wall at cantilever base and the vertical . . . . . degrees

ϕ = angle between face of dam and the vertical . . . . . degrees

α = angular movement of abutment in vertical plane due to unit bending moment, ${}_AM_x$ . . . . . radians

γ = abutment movement normal to axis of dam due to unit shear force at abutment . . . . . ft

α_2 = angular movement of abutment in vertical plane due to unit horizontal shear force at the abutment . . . . . radians

α_2 = abutment movement normal to axis of dam due to unit bending moment, ${}_AM_x$ . . ft

δ = angular movement of abutment in horizontal plane due to unit twisting moment, ${}_AM_{xy}$, at abutment . . . . . radians

The values of a, α_2, γ, and δ are determined from curves and equations given in Chapter III of Bulletin 1, Part V of the Boulder Canyon Project Final Reports.

Positive normal loads act downstream.

Positive deflection is upstream.

Positive shears in longitudinal vertical planes act downward on the portion nearest to the upstream face.

Positive shears in horizontal planes act downstream on the portion above the plane.

Positive twisting moments and bending moments in horizontal planes act counterclockwise when viewed from above when dealing with the right abutment of the structure, and tend to produce compression on the upstream face.

(.113)
Positive bending moments and twisting moments in vertical planes tend to produce compression at the upstream face.

.114 The following general procedure is usually followed in making a trial-load twist analysis for a straight gravity dam, assuming joints not grouted: PROCEDURE

A. Study the layout drawing of the site showing the location of the axis of the dam, the profile of the canyon along the axis or a face, the topography, excavation limits, etc. If the dam is reasonably symmetrical with respect to the canyon, divide it at the vertical plane of symmetry normal to the axis of the dam. In this case, only half of the dam need be analyzed. If it is not symmetrical, it is divided at any convenient plane near the center where the canyon floor is relatively flat, or where it is suspected that no great amount of twist action should exist in the dam. Each part of the structure is analyzed separately and brought into adjustment. In order to maintain the continuity of the structure, both parts of the dam must have the same deflections at the dividing plane. DIVISION OF DAM FOR ANALYSIS

B. Select five to seven horizontal beam elements, and a sufficient number of cantilever elements to represent the structure. For steeply sloping abutments, extra cantilevers may be added to study the effect of twist at this location. The locations of the beams and cantilevers should be such that the bases of the cantilevers and the ends of the beams coincide at the abutments. The locations of these elements will depend on the length, depth, symmetry, and regularity of the site. SELECTION OF BEAM AND CANTILEVER ELEMENTS

C. Compute the forces and moments due to each of the following loads on the cantilever elements, for each beam elevation. COMPUTATION OF FORCES AND MOMENTS

(1) Dead loads
(2) Vertical components of water loads
(3) Vertical components of earthquake loads
(4) Horizontal components of water loads
(5) Horizontal components of earthquake loads

(.114)

STRUCTURAL PROPERTIES OF CANTILEVERS

D. Compute the quantities, A, I, and J at each beam elevation for the cantilever elements. The values of J are computed from the equation.

$$J = \beta b c^3 \qquad \text{.....(1)}$$

where b = the longer side of a horizontal cross-section of a rectangular block between construction joints.

c = the shorter side of a horizontal cross-section of a rectangular block between contraction joints,

and β is obtained from the curve in Figure 32.

To determine J for a cantilever 1-foot wide, the computed values of J are divided by the distance between contraction joints.

ABUTMENT MOVEMENTS

E. Compute the unit abutment movements, a, γ, α_2, and δ for each cantilever or beam abutment, using equations and graphs given in Chapter III, Bulletin 1, Part V of Boulder Canyon Project Final Reports.

INITIAL CANTILEVER DEFLECTIONS

F. Compute the "initial" cantilever deflections which include the effects of vertical components of reservoir, tailwater, and earthquake water loads and the inertia effects of earthquake on dead loads and horizontal water loads. They may be computed by the following formula:

$$\Delta y = \Sigma\left(\Sigma \frac{M_x}{EI} \Delta z + {}_A M_x \alpha + {}_A V_c \alpha_2\right) \Delta z$$

$$+ \left(\Sigma \frac{K}{G} \frac{V_c}{A} \Delta z + {}_A V_c \gamma + {}_A M_x \alpha_2\right) \quad \text{.....(2)}$$

The computation may be facilitated by the use of the computation form shown in Figure 33.

(.114F)

As stated previously, the cantilever deflections in the trial-load apportionment of external loads are measured from the initial deflected positions due to vertical water and earthquake loads. The twisted structure deflections are measured from the zero positions of the cantilevers and twisted structure. In this way, the effects of the vertical components of external load are distributed between the two structural systems of elements in the trial-load adjustment.

INITIAL CANTILEVER DEFLECTIONS (CONT.)

G. Compute the forces and moments, and the normal deflections of the cantilevers due to a system of unit normal loads similar to those shown in Figure 34. The unit loads are similar to those described in Chapter IV of Bulletin 1, Part V of the Boulder Canyon Project Final Reports. The deflections are computed by means of equation (2).

NORMAL FORCES AND MOMENTS

H. Compute the twisting moments and angular rotations of the cantilevers due to a system of unit twist loads similar to those shown in Figure 34. The angular rotations of the cantilevers in horizontal planes due to the unit couple loads are computed by the equation:

TWISTING MOMENTS AND ROTATIONS

$$\theta_z = \Sigma \frac{M_{xy}}{GJ} \Delta z + {}_A M_{xy} \delta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

I. Compute the shear forces due to the system of unit shear loads carried by the twisted structure in each horizontal beam element at the several points of intersection with the cantilever elements. The types of unit loads used in the analysis are shown in Figure 35. These shear forces are equal to the area under the unit load diagram from the dividing plane of the dam to the cantilever points under consideration. The shear force in the horizontal beam at any cantilever point is also equal to the twisting couple in a cantilever 1-foot wide at that point. In this way, the twisting couples in the cantilevers at each beam elevation can be determined. The concentrated load is used to restore continuity to the cut structure because both ends of the cut horizontal element must be brought into deflection agreement. Only a concentrated shear load is required because there is no bending and resulting rotations due to shear.

SHEAR FORCES IN BEAM ELEMENTS

(.114)

SHEAR DEFLECTIONS IN BEAM ELEMENTS

J. Compute the normal shear deflections due to the unit shear loads described in the preceding paragraph. The deflections are given by the following formulas:

For the unit triangular load:

$$\Delta y = \frac{KP}{2AGL'}\left[(L')^2 x - L'x^2 + \frac{x^3}{3}\right]_0^x + \frac{PL'}{2}\gamma \quad \ldots\ldots (4)$$

For the unit uniform load:

$$\Delta y = \frac{KP}{AG}\left[Lx - \frac{x^2}{2}\right]_0^x + PL\gamma \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5).$$

For the unit concentrated load:

$$\Delta y = \frac{KP}{AG}\left[x\right]_0^x + P\gamma \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6).$$

TOTAL ANGULAR ROTATIONS IN CANTILEVERS

K. The twisting couples which were computed in Paragraph .114-I represent the maximum ordinates of a system of triangular twist loads applied at the different beam elevations in the cantilevers. Since the unit couple loads were assigned a value of P = 1,000 foot-pounds per square unit, the couple loads computed in Paragraph .114-I should also be multiplied by 1,000. Multiplying these ordinates by the angular rotation in the cantilever (computed from equation (3)) due to unit twist loads at corresponding points, gives the total angular rotations in the cantilevers due to the unit shear forces on the beams. In this way, the twisting effect due to a shear force carried by a cantilever element is transmitted to all other parts of the twisted structure above and below the load.

TWISTED STRUCTURE DEFLECTIONS

L. Compute the deflections of the twisted structure due to the angular rotations of the cantilevers by adding the rotations, computed in the preceding paragraph, along the horizontal beams from the abutments to the dividing plane of the dam. This summation process gives the deflection of the twisted structure at each beam elevation due to twists in the cantilevers.

(.114)

M. The deflections of the twisted structure due to twist in the cantilevers and the deflections of the horizontal beam elements due to shear, as described in Paragraph .114J are added algebraically at corresponding points. The sum of these deflections at a given point represents the total twisted structure deflection due to the twisted structure load.

TOTAL TWISTED STRUCTURE DEFLECTIONS

N. The next step in the analysis is to make the actual trial-load division of the horizontal components of external loading between the two systems of elements. There is no rule that can govern this apportionment of load between the two systems. It is, as the name implies, a "trial" proposition. However, it has been found by experience that the cantilevers carry the greater proportion of water load, especially near the central portion of the dam. The adjustment of an ordinary gravity dam is one which does not require an irregular load pattern; that is, one with high concentrations of positive or negative loads, irregularly placed. The adjuster should be satisfied that his loading is the least possible application of load that will bring the two structures into adjustment. The adjustment is carried out by applying load to and computing deflections in the twisted structure and cantilever structural systems. The total twisted structure deflections are the algebraic sums of those due to trial proportions of the external loads multiplied by the unit load deflections described in Paragraph .114M, and the abutment deflections of the cantilever bases coinciding with the ends of the beams. The total cantilever deflections are those due to the remaining portions of the horizontal external loads multiplied by their respective unit normal load deflections, the initial deflections of the cantilevers, and the abutment shear deflections of the horizontal beams which abut with the bases of the cantilevers. In the latter case, the abutment deflections of the cantilever and beam abutments are always made coincident at common points.

TRIAL-LOAD ADJUSTMENT

O. After satisfactory continuity of the two structural systems has been achieved at conjugate points, the total shears and moments at all points of the cantilevers may be computed by summing up the total effects of the trial loadings on the cantilevers. These are obtained by adding the loadings times the unit moments and thrusts due to the 1,000-pound unit loads described in Paragraph .114G.

TOTAL CANTILEVER SHEARS AND MOMENTS

(.114)

COMPUTATIONS OF STRESSES

P. The normal stresses, σ_z, are then computed in the usual manner, described in Paragraph 5.2.107. The inclined or principal stresses at the faces are found by the following equation:

$$\sigma_I = \sigma_z \sec^2 \phi - p \tan^2 \phi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

COMPUTATION OF STABILITY FACTORS

Q. Equations for stability factors can be found in Paragraph 5.2.107. In computing the stability factors on inclined abutment planes the total shearing force is due to the shear from the 1-foot wide cantilever element plus the shear from the abutting 1-foot wide horizontal element of the twisted structure, which must be corrected for its actual abutting width as illustrated in Figure 36. The total inclined abutment shear is therefore

$$V_A = V_c + V_t \cot \psi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

The total resisting force normal to the inclined abutment plane is equal to the resultant of the total vertical forces and horizontal thrust assumed from the adjacent cantilever elements as shown by the force triangle in Figure 36. This normal force becomes

$$\Sigma(W + U) \csc \psi$$

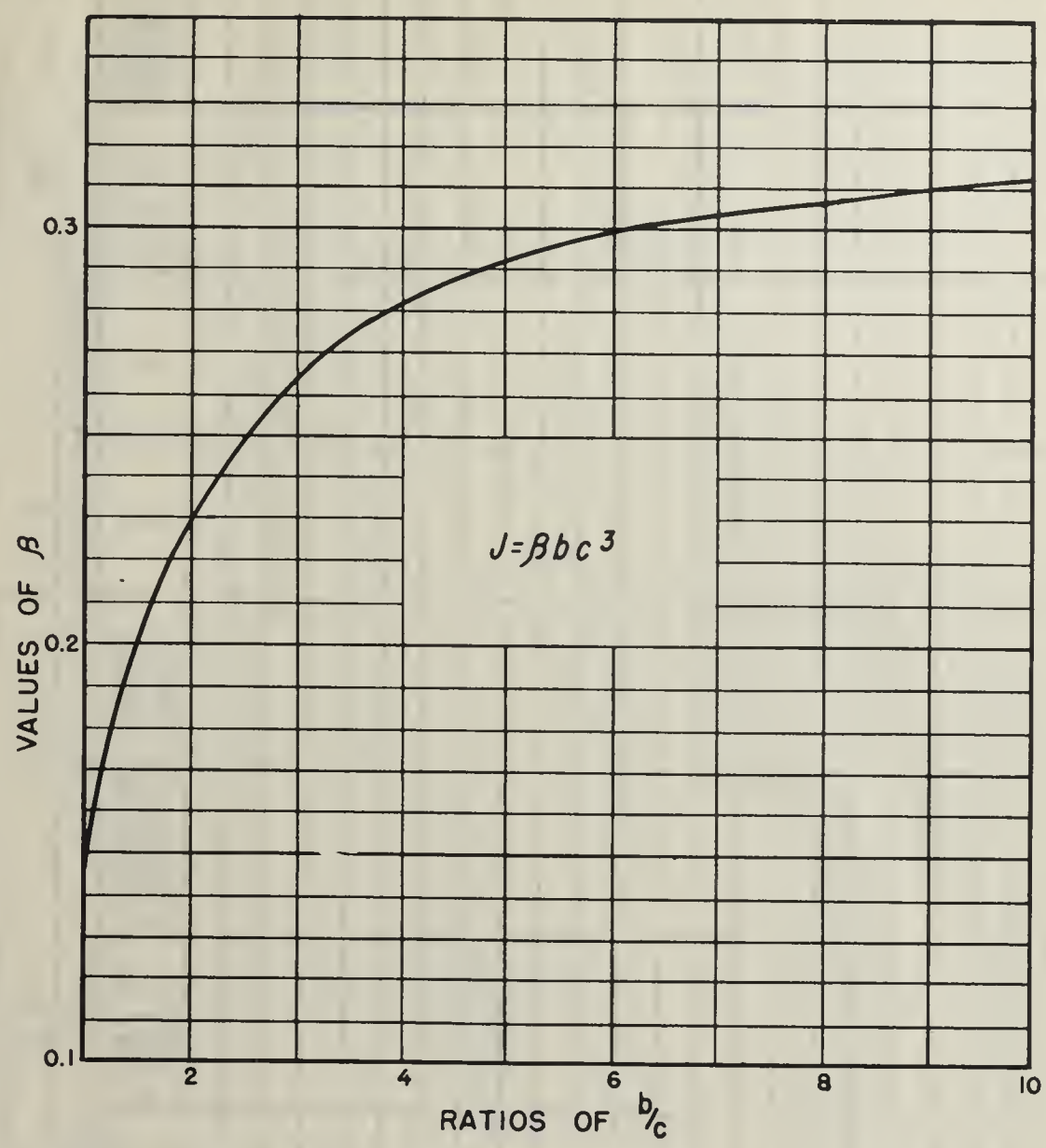
The sliding factor for an inclined abutment plane is then computed by the equation:

$$(S.F.)_A = \frac{V_A}{\Sigma(W + U) \csc \psi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

and the shear-friction factor for an inclined abutment plane is computed by the equation:

$$Q_A = \frac{\Sigma(W + U) \csc \psi \, (f) + A's}{V_A} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

FIG. 32 par. 5.2.114



b= longer side

c= shorter side

Data for determining factor "J" due to twist of a shaft of rectangular cross-section taken from Timoshenko's "Strength of Materials", Part I, page 77.

UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION	
TRIAL LOAD TWIST ANALYSIS DATA FOR TWIST FACTOR "J"	
BY J. P. M.	JUNE 20, 1946
APV. C. R.	MD-DT-6

α = ...

α_2 = ...

τ = ...

Θ = ... δ = ...

.....DAM.....SECTION STUDY NO. .....

.....*PARALLEL*.....SIDE CANTILEVER STRESS ANALYSIS.....

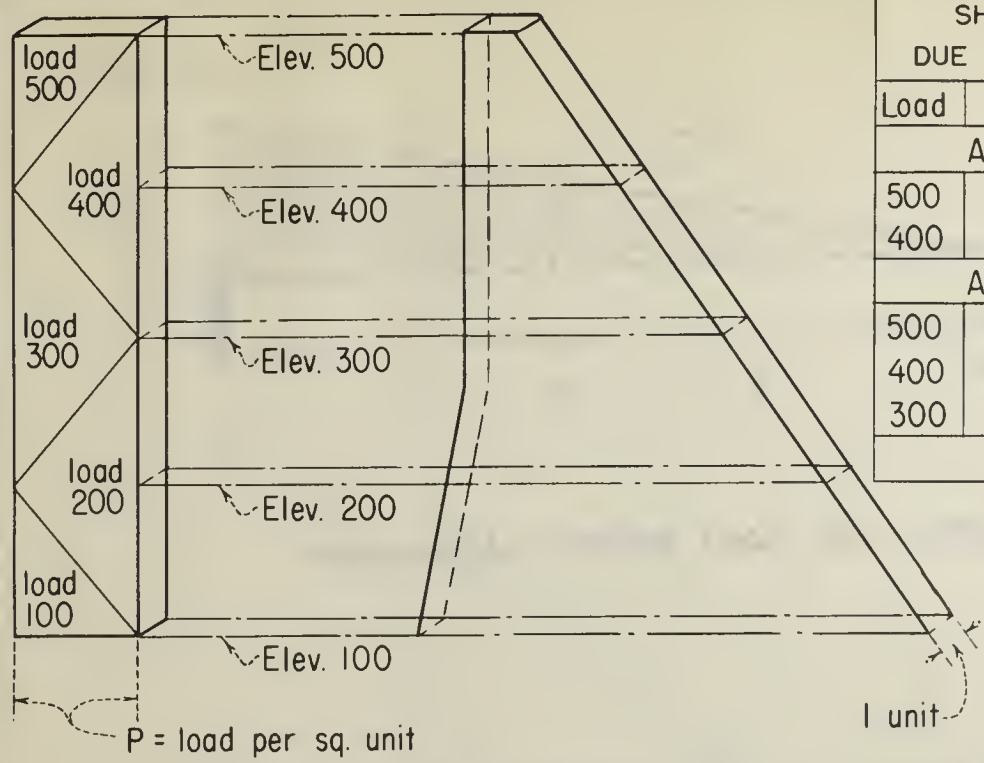
.....DEFLECTION.....LOAD NO. ..... CANTILEVER .....

$\frac{I}{E}$ = ... $\frac{K}{G}$ = $\frac{}{G}$ = ... By ..... Date .....

Elev.	Deflection due to *Bending*						Deflection due to *Shear*					Total Deflection
	Moment = M	$\frac{I}{EI}$	$\frac{M}{EI}$	$\frac{\Delta Z}{2}$	$\sum\left(\frac{M}{EI}\right)\frac{\Delta Z}{2}$	$\sum\frac{\Delta Z}{2}\left(\sum\frac{M}{EI}\frac{\Delta Z}{2}\right)$	Horizontal Force = V	$\frac{I}{A}$	$\frac{V}{A}$	$\left(\frac{K}{G}\right)\frac{\Delta Z}{2}$	$\sum\left(\frac{V}{A}\right)\left(\frac{K}{G}\frac{\Delta Z}{2}\right)$	

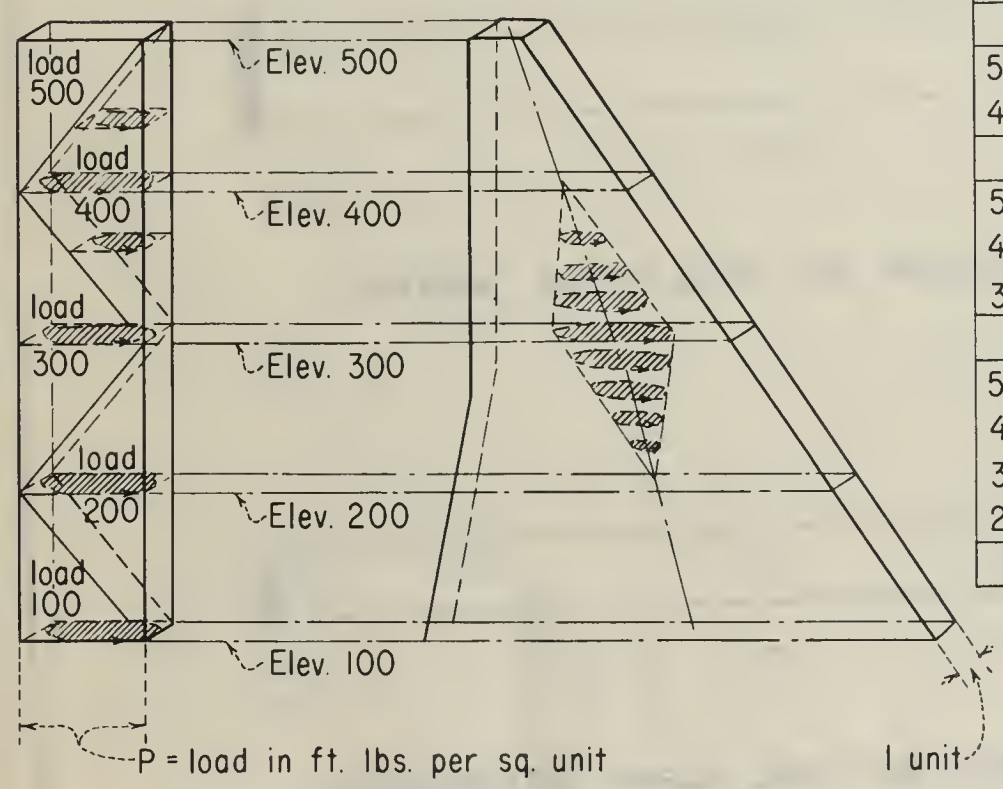
FIG. 33 par 5.2.114

FIG. 34 par. 5.2.114



UNIT NORMAL LOADS ON CANTILEVER

SHEARS AND MOMENTS DUE TO UNIT NORMAL LOADS		
Load	ΔV	ΔM_x
At Elevation 400		
500	$\frac{P}{2}\cdot 100$	$\frac{P}{2}\cdot 100\cdot\frac{2}{3}\cdot 100$
400	$\frac{P}{2}\cdot 100$	$\frac{P}{2}\cdot 100\cdot\frac{1}{3}\cdot 100$
At Elevation 300		
500	$\frac{P}{2}\cdot 100$	$\frac{P}{2}\cdot 100(\frac{2}{3}\cdot 100+100)$
400	$\frac{P}{2}\cdot 200$	$\frac{P}{2}\cdot 200\cdot 100$
300	$\frac{P}{2}\cdot 100$	$\frac{P}{2}\cdot 100\cdot\frac{1}{3}\cdot 100$
Etc.		



POSITIVE UNIT TWIST LOADS ON CANTILEVER

TWISTING MOMENTS DUE TO UNIT TWIST LOAD	
Load	ΔM_{xy}
At Elevation 400	
500	$\frac{P}{2}\cdot 100 = 50P$
400	$\frac{P}{2}\cdot 100 = 50P$
At Elevation 300	
500	$\frac{P}{2}\cdot 100 = 50P$
400	$\frac{P}{2}\cdot 200 = 100P$
300	$\frac{P}{2}\cdot 100 = 50P$
At Elevation 200	
500	$\frac{P}{2}\cdot 100 = 50P$
400	$\frac{P}{2}\cdot 200 = 100P$
300	$\frac{P}{2}\cdot 200 = 100P$
200	$\frac{P}{2}\cdot 100 = 50P$
Etc.	

NOTES

ΔV = Horizontal force of portion of load above an elevation.

ΔM = Bending moment of ΔV about an elev.

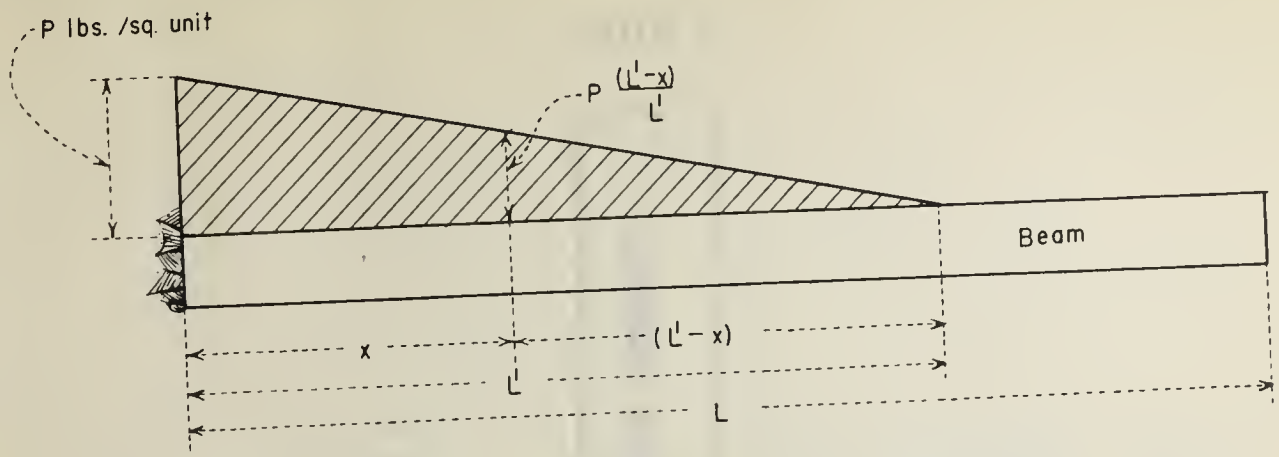
ΔM_{xy} = Twisting moment in horizontal xy plane due to portion of the twist load above an elevation.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

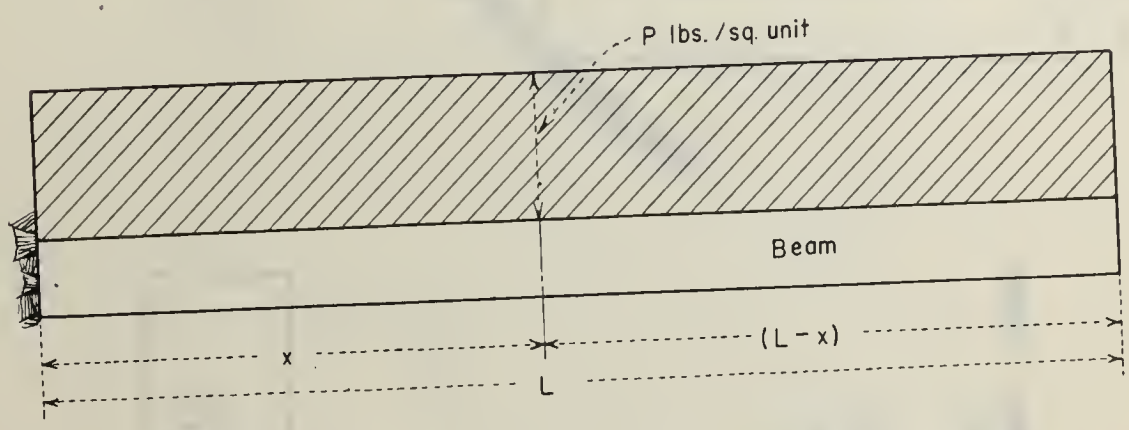
TRIAL LOAD TWIST ANALYSIS
STRAIGHT GRAVITY DAM
UNIT LOADS ON CANTILEVER ELEMENT

BY	W.A.T.	JUNE 28, 1946
APV.	C.R.	MD-DT-7

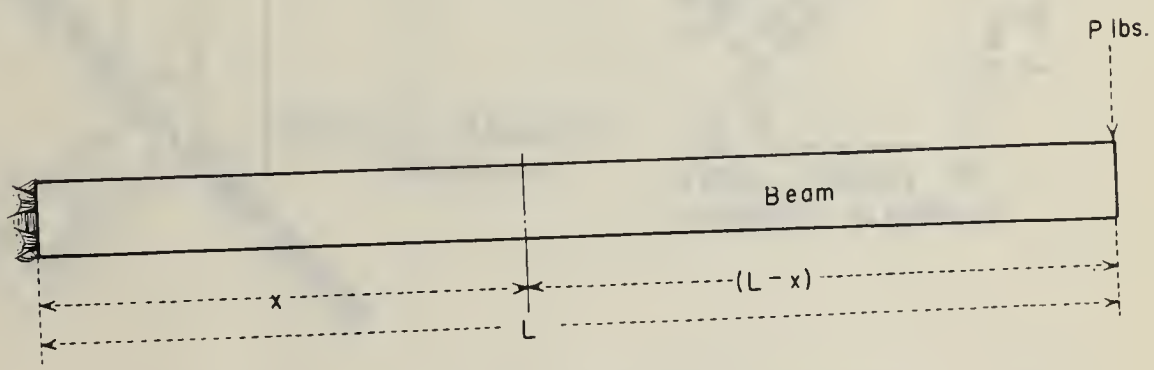
FIG. 35 par. 5.2.114



TRIANGULAR SHEAR LOAD ON HORIZONTAL BEAM



UNIFORM SHEAR LOAD ON HORIZONTAL BEAM



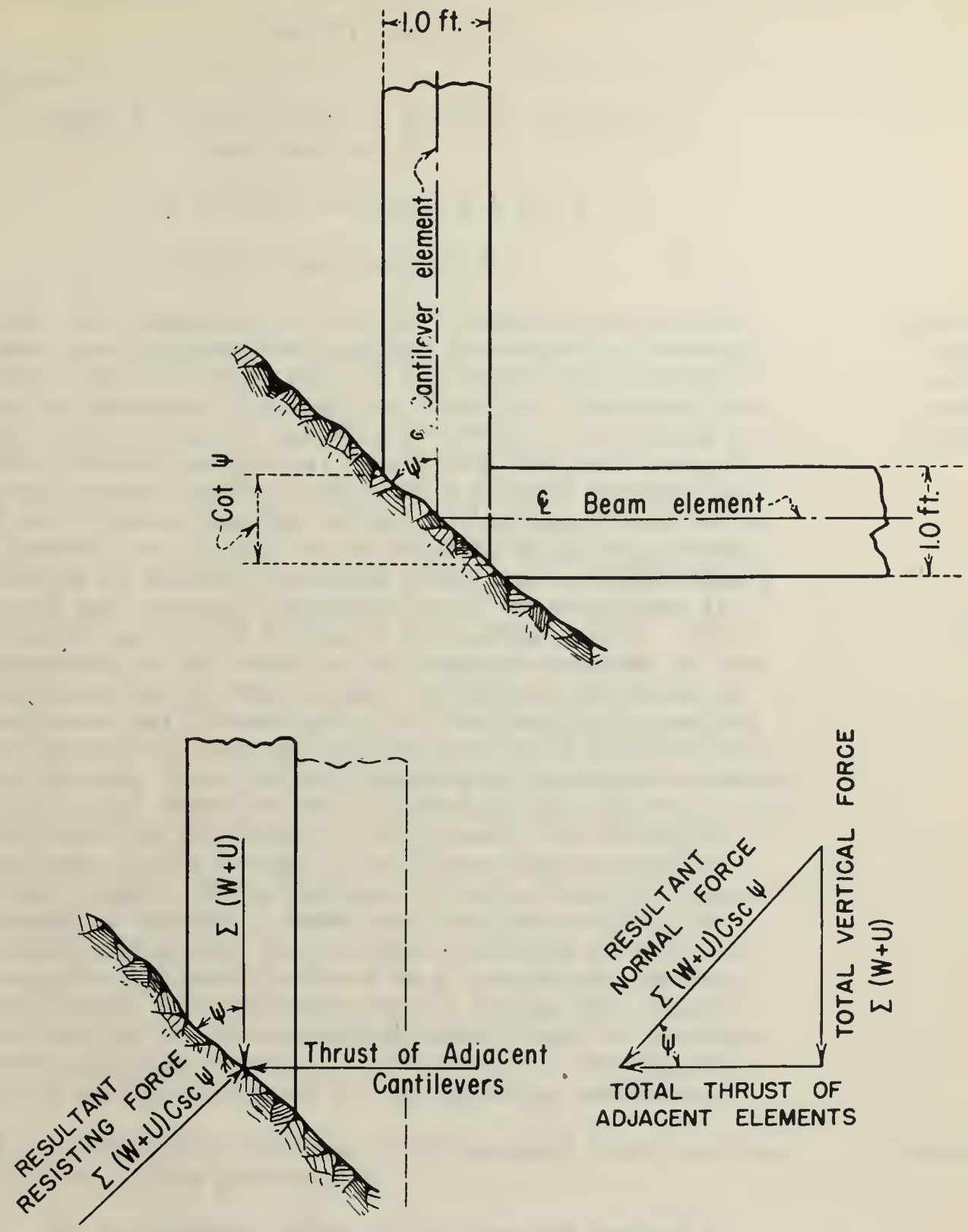
CONCENTRATED SHEAR LOAD ON HORIZONTAL BEAM

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

TRIAL LOAD TWIST ANALYSIS
STRAIGHT GRAVITY DAM
UNIT SHEAR LOADS ON BEAM ELEMENTS

BY F.A.H. T.M.C.	AUGUST 22, 1946
APR. C.R.	MD-DT-18

FIG. 36 par. 5.2.114



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

TRIAL LOAD TWIST ANALYSIS

CONTACT OF BEAM AND CANTILEVER WITH ABUTMENT

BY	F.A.H.	JUNE 21, 1946
APV.	C.R.	MD-DT-12

(.114Q)

where f = coefficient of internal frictional resistance = 0.65

A' = inclined base area = A csc ψ

s = unit shear resistance.

.115 When the contraction joints of a straight gravity dam have been grouted, the keys may be assumed to transfer shears vertically as well as laterally. Furthermore, as the dam acts as a monolith, both the horizontal and vertical systems of elements are subject to bending in their respective planes. Therefore, any twist analysis that is made for the condition of grouted contraction joints, neglecting the effects of bending in horizontal elements, can be only an approximate solution, because studies of several dams have shown that a comparatively small but appreciable proportion of external load is transmitted to the abutments by bending action. The magnitude of the error in the computed stresses at the abutment regions when flexure in horizontal planes is neglected may be negligible or considerable, depending on the size of the dam and the profile of the damsite. In general, the effects of bending of horizontal elements on the load distribution for straight gravity dams may be neglected in the design of small dams, but should be included in the design of all large dams and dams of great length. The advantages of neglecting the flexural effect in horizontal beams are that the analysis is greatly simplified and the time necessary to make the analysis is thereby reduced by a considerable amount. The methods and procedure used in making this analysis are similar to those previously explained for the case with ungrouted contraction joints with a few exceptions which will be explained in the following paragraphs.

TRIAL-LOAD TWIST ANALYSIS, JOINTS GROUTED

.116 The assumptions underlying the trial-load twist analysis with the joints grouted are:

ASSUMPTIONS

A. The contraction joints in the dam are assumed to be thoroughly grouted and the dam acts as a monolith.

B. The contraction joints transfer shears horizontally and vertically.

C. The cantilevers can twist in horizontal planes and the horizontal beams can twist in vertical planes.

(.116)

D. The cantilevers are subject to bending in vertical planes, but the effects of bending of the horizontal beams in horizontal planes are neglected.

E. The twisted structure resists torsions in both the vertical and horizontal planes.

NOMENCLATURE

.117 The nomenclature used for making this analysis is the same as that used for the analysis assuming joints not grouted, except that it is no longer necessary to apply the factor J to the shear moduli in computing angular rotations of cantilevers due to torsions.

PROCEDURE

.118 The procedure for making this analysis is the same as that previously explained in Paragraph 5.2.114 with the exceptions noted below:

ANGULAR ROTATIONS OF CANTILEVERS

A. The equation,

$$\theta_z = \Sigma \frac{M_{xy}}{2GI} \Delta z + {}_A M_{xy} \delta \quad \text{.....(11)}$$

is used instead of equation (3), Paragraph .114H, for computing the angular rotations of the cantilever elements in horizontal planes.

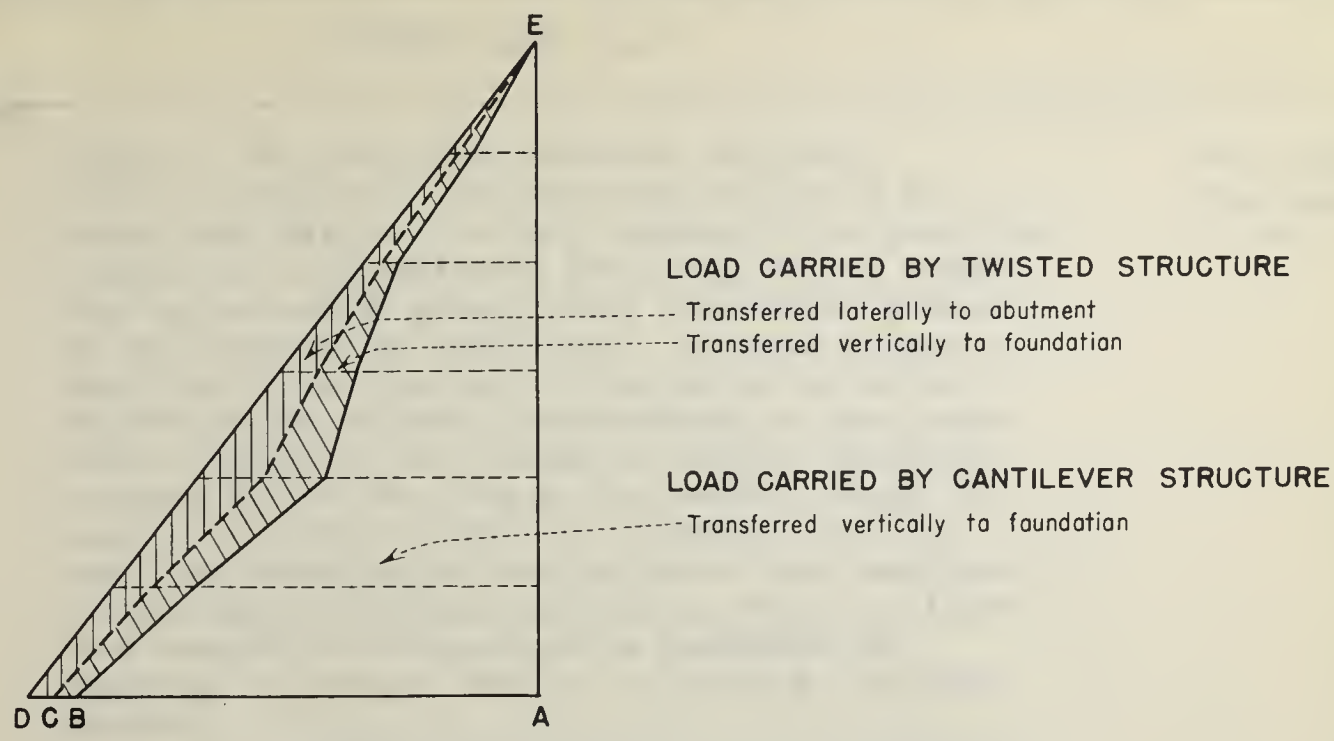
TRANSFER OF TWISTED STRUCTURE LOAD

B. In the analysis of a dam with the contraction joints grouted, one-half of the load carried by the twisted structure is transferred horizontally to the abutments and the remaining half is transferred vertically to the foundation.

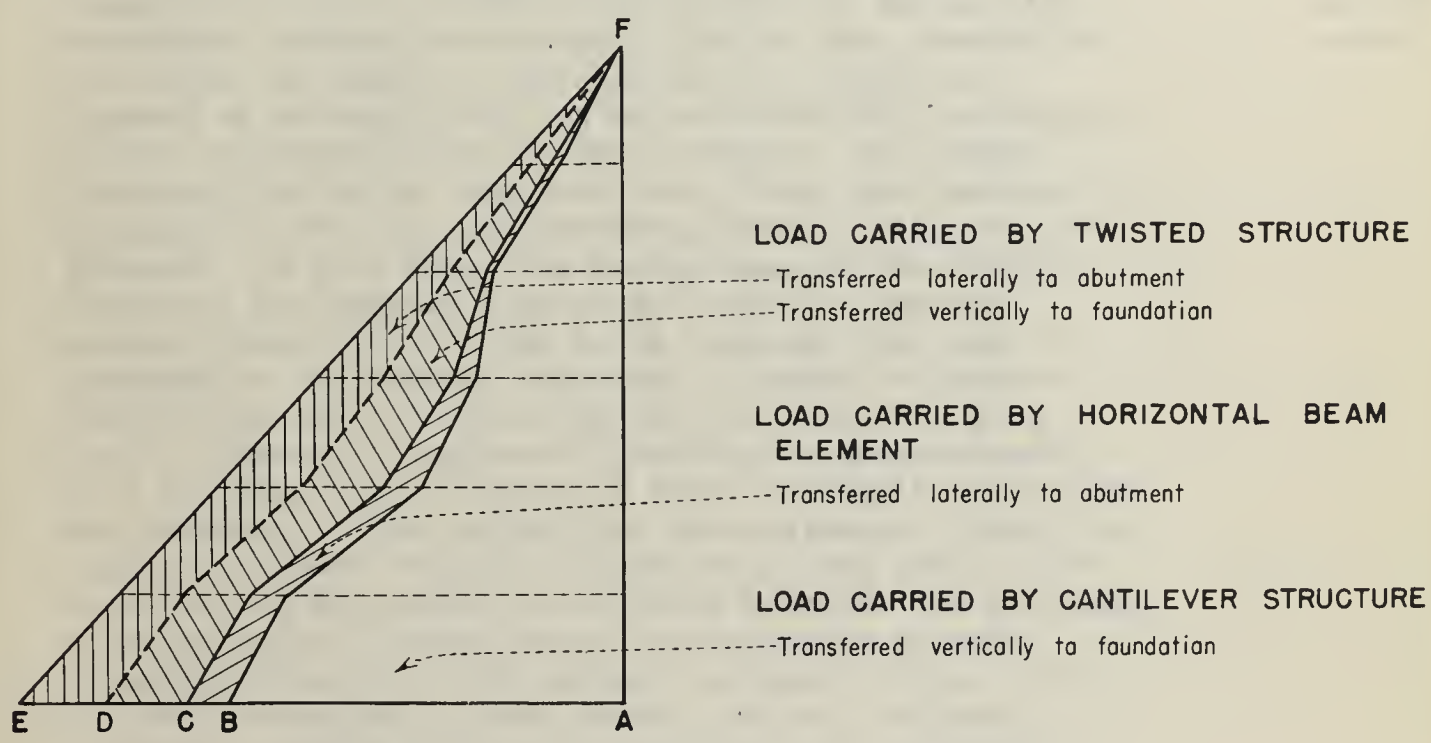
TRIAL-LOAD APPORTIONMENT

C. The division of external horizontal loads between the cantilevers and twisted structure, by trial, is represented in Figure 37A, showing a water pressure diagram, triangle DAE, for a typical vertical cantilever element in a gravity dam. The total portion of the water load carried by the twisted structure is shown by the portion DBE. Of this amount, one-half, DCE, is transferred laterally to the abutment by horizontal shear forces acting along vertical transverse sections of the horizontal elements and by twisting couples acting in the unit horizontal planes of the cantilever. The other half, CBE, is transferred vertically to the foundation by additional shearing forces acting horizontally along horizontal transverse sections of the cantilever and by twisting couples in the unit vertical transverse

FIG. 37 par. 5.2.118



A — NEGLECTING EFFECTS OF HORIZONTAL BEAM ACTION IN BENDING



B — INCLUDING EFFECTS OF HORIZONTAL BEAM ACTION IN BENDING

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

TRIAL LOAD TWIST ANALYSIS
STRAIGHT GRAVITY DAM — JOINTS GROUTED
DIVISION OF EXTERNAL HORIZONTAL LOADS

BY F.A.H. T.M.C.	AUGUST 23, 1946
APR. C.R.	MD-DT-19

(.118C)

TRIAL-LOAD APPORTIONMENT (CONT.)

planes of the horizontal beams in the plane of the cantilever. The remaining portion of the water load, BAE, is the part carried by the cantilever element and is transferred vertically to the foundation by horizontal shear forces and bending moments in the plane of the cantilever. In other words, in the actual trial loading of the dam, a system of twisted structure loads corresponding to the amount DCE is applied to the horizontal twisted structure elements of the dam. Twice this amount, which is equal to the portion DBE, is subtracted from the total horizontal water load acting on any cantilever to give the portion BAE, carried by that cantilever. This transfer of forces must be remembered in computing the shears used in calculating stability factors.

EFFECT OF GROUTING ON TWIST ACTION

.119 The general effect of grouting the contraction joints is to consolidate the blocks into a monolithic mass, the character of which is three-dimensional as far as its structural action is concerned. Due to the cohesion of its parts, the dam has an indefinite but important element of strength that may be satisfactorily explained by the foregoing theory of twist action. The theory provides, and actual analyses show, that twist action is intensified when the construction joints of the dam are grouted. In this case, the deflections of the twisted structure are greatly reduced so that considerably greater proportions of the total external load must be assigned to the twisted structure in order to produce deflections equal to those in the cantilevers. More load is thereby transferred laterally to the abutments, thus increasing the effects of twist on stability factors and stresses in the vicinity of the abutments. Also, in cases where dams include comparatively long central sections having approximately constant heights, the grouting of construction joints causes the extension of twist effects farther into the central section. If the joints are left ungrouted in such cases, the twist effects disappear rapidly beyond the bottoms of the abutment slopes.

PRACTICAL CONSIDERATIONS

.120 The elimination of twist action in a straight gravity dam is not entirely desirable because a considerable amount of water load being transferred by this action alleviates the loads carried by the cantilevers in certain sections and is certainly beneficial. On the other hand, intensification of twist effects near steep sloping abutments and in the upper abutment regions of a dam has the tendency to twist the sections of the

(.120)

PRACTICAL CONSIDERATIONS (CONT.)

dam in those regions from the sloping bases and produce diagonal cracking in the concrete. It appears, therefore, that leaving certain joints ungrouted or providing twist slots to constitute definite barriers to the extension of twist and bending action would be a logical means of overcoming detrimental twist action. Practicable difficulties, however, are involved in such a procedure, because of tendencies toward unequal settlement of the blocks and danger of abutment sections sliding down steep slopes toward the central section.

TRIAL-LOAD TWIST ANALYSIS, JOINTS GROUTED, BENDING INCLUDED

.121 If beam action in bending is considered in the trial-load twist analysis, the total external water pressure on the dam is assumed to be carried by three systems of load transfer, namely the cantilever structure system, the twisted structure system, and the longitudinal-beams structure system. For the purpose of making this analysis, the dam is assumed to be replaced by these three systems of structural elements, each identical with the dam, instead of the two systems that were used in the analysis which omitted the effects of horizontal flexure.

ASSUMPTIONS

.122 The assumptions given here form the basis of the trial-load twist analysis when joints are grouted and flexural effects are included:

A. The cantilever elements resist shears in horizontal planes and bending in vertical planes.

B. The horizontal beam elements resist shears in vertical planes and bending in horizontal planes.

C. The twisted structure elements resist the twisting moments in both horizontal and vertical planes.

CONDITIONS OF COMPATIBILITY

.123 If the dam acts as a monolith, as assumed, the deflections of the cantilevers, horizontal beams, and the twisted structure due to trial divisions of the total water loads between the three systems of load transfer must be brought into satisfactory agreement in all parts of the dam. Furthermore, to be strictly correct, the longitudinal slopes of the cantilevers must equal the transverse slopes of the horizontal elements and longitudinal slopes of the horizontal elements must equal the transverse slopes of the cantilevers. The adjustment of slopes, however, is rarely undertaken in an analysis not only because of the added complications to an already complicated procedure, but because investigations in early analyses including this refinement have proved that resulting change in division of load has been slight.

.124 The procedure used in making this type of analysis is quite similar to the procedure previously described for cases where the joints are grouted, but beam action is neglected. However, the adjustment is more complicated because continuity must be restored between three systems of structural elements instead of the two in the preceding analysis. Part of the horizontal component of water load is first divided between the twisted structure and the horizontal beam elements. The remaining part of the load is assigned to the vertical cantilever system. The division at a typical cantilever element is represented in Figure 37B, showing a horizontal water pressure diagram and the portion of the total load taken by each of the three structural elements. The portion CBF represents the amount of horizontal water load transferred by the horizontal beam elements in bending and shear. The portion ECF represents the total portion of the water load carried by the twisted structure. As previously explained in Paragraph 5.2.118, one-half of the load taken by the twisted structure is transferred laterally to the abutments, and the other half is transferred vertically to the foundation. PROCEDURE

A. Horizontal beam elements are usually assumed to be 1-foot high, with horizontal top and bottom faces and vertical upstream and downstream edges. The beams are statically indeterminate elements terminating at elastic abutments. Calculations of deflections of beam elements are made by the ordinary theory of flexure for beams with contributions from abutment yielding included. A summary of deflection equations and methods of computation will be given in subsequent paragraphs. The same types of unit loads used in the trial-load twist analyses described previously are used for the same functions in this analysis. In addition, a new system of unit loads is employed for determining the proportions of load transferred by bending and shear in the horizontal beam system of elements. Types of beam loads include a unit uniform normal load over the entire beam length, triangular normal loads varying in pressure from a maximum at a beam fractional point to zero pressure at adjacent fractional points, as shown in Figure 38A, and concentrated normal loads applied at the beam abutments. The function of the different types of unit loads is exactly the same as described in detail in Chapter II of Bulletin 1, Part V, of the Boulder Canyon Project Final Reports. HORIZONTAL FLEXURE ELEMENTS

(.124)

SOLUTION OF STATICALLY-INDETERMINATE BEAM

B. In Figure 38B, the center or the point where each beam is assumed to be cut, has been designated the "crown" of the beam. By cutting the beam thus, and restoring it to equilibrium and continuity by the system of forces and moments V_o and M_o, respectively, the beam is statically determined, and solution is facilitated.

ADDITIONAL NOMENCLATURE

C. It is now desirable to introduce the additional system of nomenclature to be used with the subsequent solution. Figure 38B shows one-half of a unit horizontal beam element loaded with a unit triangularly-distributed normal load and in equilibrium with a shear force, V_o and a moment, M_o, applied at the crown. Referring to this figure:

x, x_o, x_1, x_2, = coordinates defining the limits of a unit triangular load pattern, measured from the crown.

x_p = distance between the crown and a point on the beam centerline where the deflection is desired.

x' = distance measured from point where deflection is desired to any beam point.

x_a = the length of the beam (crown to abutment.)

M_o, V_o, = moment and shear, respectively, at the crown.

M_L, $\cancel{M}_L$, V_L, = moment, twisting moment, and shear, respectively, at any point, due to the external load to the right of that point, for the left half of the beam.

θ = angular movement of centerline in horizontal plane.

Δy = normal deflection of centerline in horizontal plane.

α = angular movement of abutment in horizontal plane due to unit horizontal bending moment, M_A.

(.124C)

ADDITIONAL NOMENCLATURE (CONT.)

γ = deflection normal to axis of dam of abutment due to unit sheer, V_A.

α_2 = angular movement of abutment in horizontal plane due to unit shear, V_A.

α_2 = deflection normal to axis of dam due to unit horizontal bending moment, M_A.

The values of α, γ, and α_2 are determined from curves and equations given in Chapter III of Bulletin 1, Part V, of the Boulder Canyon Project Final Reports.

EQUATIONS FOR MOVEMENT OF BEAM

D. The general equations for the rotation and deflection of any point in a horizontal beam element, including effects of bending, shear, and elastic abutments, may be written as follows:

$$\theta = \int \frac{Mdx}{EI} + M_A\alpha + V_A\alpha_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

$$\Delta y = \int \frac{Mxdx}{EI} + 3\int \frac{Vdx}{EA} + M_A\alpha x + M_A\alpha_2$$

$$+ V_A\gamma + V_A\alpha_2 x \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

Expressions for moment and shear at the crown may be obtained, the terms I and A may be expressed in terms of the cross-sectional dimensions, and after substituting the equations become:

$$\theta = M_o\left[\frac{12}{ET^3}\int dx + \alpha\right] + V_o\left[\frac{12}{ET^3}\int xdx + x_A\alpha + \alpha_2\right]$$

$$- \left[\frac{12}{ET^3}\int M_L dx + {}_AM_L\alpha + {}_AV_L\alpha_2\right] \quad \ldots\ldots\ldots\ldots \quad (14)$$

EQUATIONS FOR MOVEMENT OF BEAM (CONT.)

(.124D)

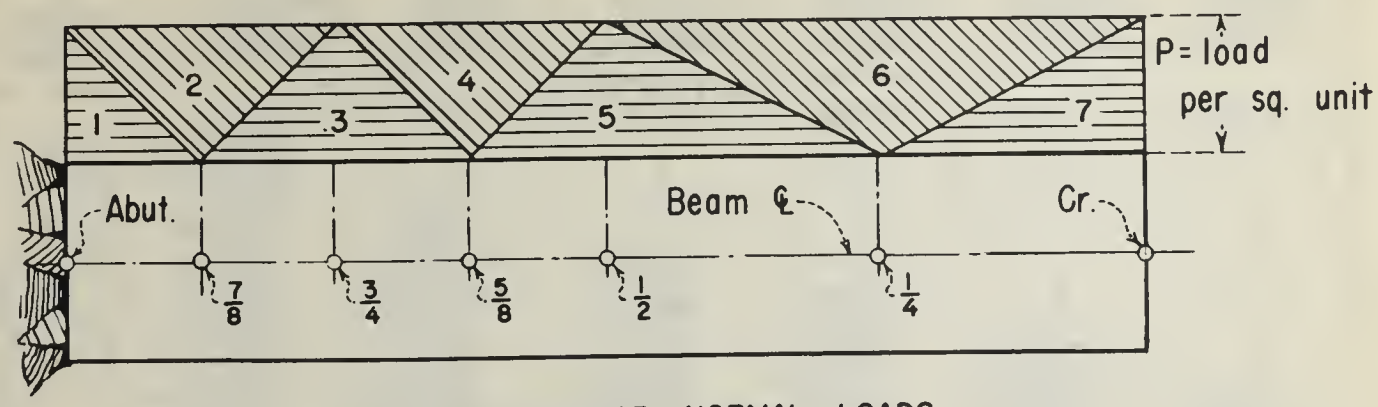
$$\Delta y = M_o \left[\frac{12}{ET^3} \int x dx + x\alpha + \alpha_2 \right] + V_o \left[\frac{12}{ET^3} \int x^2 dx + \frac{3}{ET} \int dx + x_A x\alpha + x_A \alpha_2 + \gamma + x\alpha_2 \right] - \left[\frac{12}{ET^3} \int M_L x dx + \frac{3}{ET} \int V_L dx + {}_A M_L x\alpha + {}_A M_L \alpha_2 + {}_A V_L \gamma + {}_A V_L x\alpha_2 \right]. \quad (15)$$

BEAM AND LOAD CONSTANTS

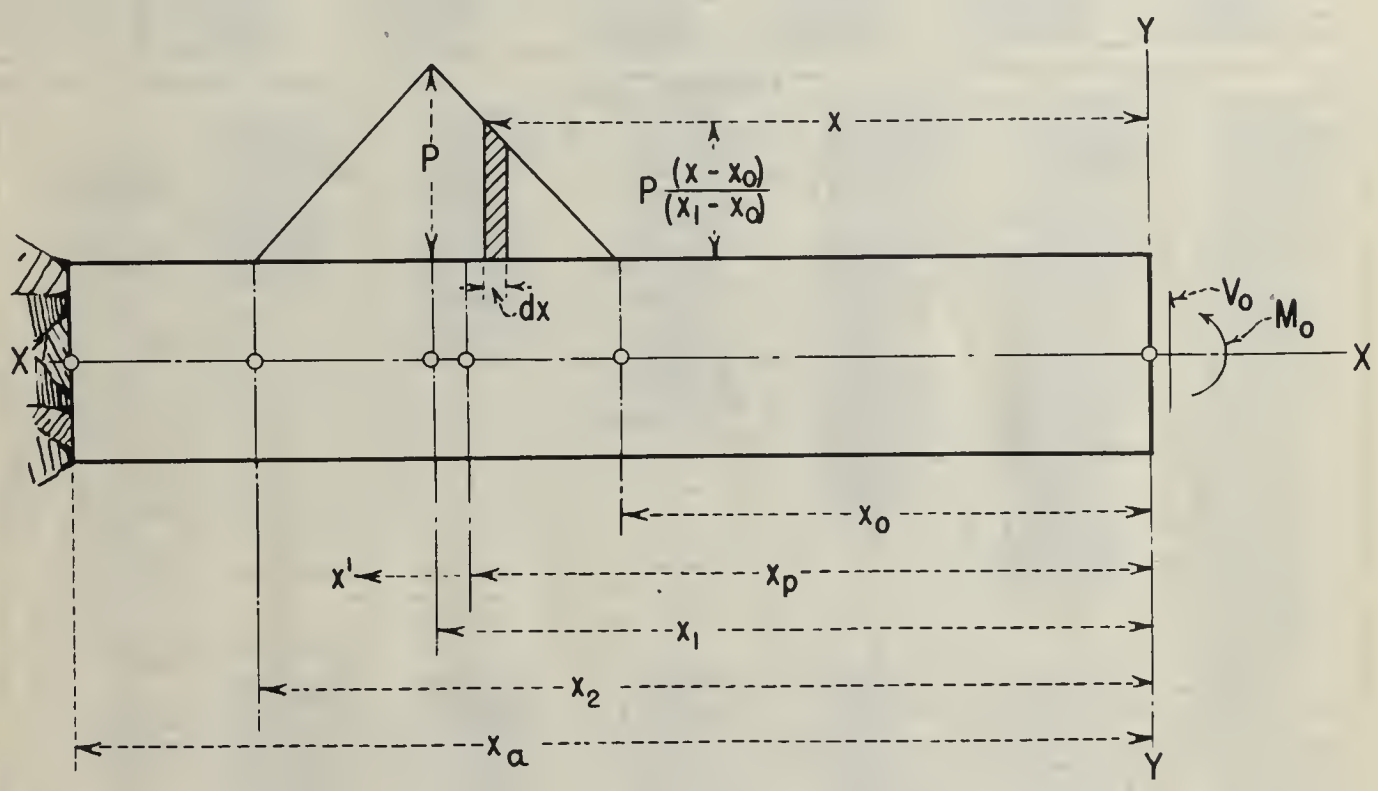
E. The beam constants and load constants have been evaluated for the triangular system of unit loads shown on Figure 38, and are presented in tabular form in Figure 39. Also, included in Figure 39 are tabulations of external load moments, M_L, shears, V_L, and twisting moments, $\overline{M}_L$, due to the unit 1,000-pound uniform or triangular system of normal or couple loads shown in Figure 38.

SUMMARY OF BEAM THEORY

F. Figure 40 is a summary of the beam theory, giving the notation, definitions, and equations for analyzing a horizontal beam element as used in this analysis. At the top of the figure is a sketch illustrating the physical properties of a uniform thickness beam, and the relative position of a unit triangular load (No. 3) on the left half. A table giving the description of the different unit loads and one indicating the directions of application of positive normal and direct couple loads and the resulting directions of positive movement of both halves of the beam are shown below the illustration. Next, a sketch shows cutaway sections of a beam to indicate directions of positive resisting forces and moments at different points along the beam due to positive loads. The direction of forces and moments due to positive loads on the left and right halves of the beam are indicated and subscript notation explained. Beam abutment movements are defined, together with equations evaluating these movements. A partial nomenclature explaining the various terms used in computing abutment movements is given, and reference is made to a bulletin in the published series of the Boulder Canyon Project Final Reports for a more complete treatment of the subject. Brief definitions of the beam and load



A - UNIT TRIANGULAR NORMAL LOADS



B - NOMENCLATURE

UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION		
TRIAL LOAD TWIST ANALYSIS UNIT LOADS ON BEAM ELEMENT		
BY	F. A. H.	JUNE 24, 1946
APV.	C. R.	MD-DT-8

FIG 39 par. 5.2.124

CONSTANTS FOR BEAM ANALYSIS

BEAM CONSTANTS

	7/8 POINT	3/4 POINT	5/8 POINT	1/2 POINT	1/4 POINT	CROWN
A_1 or A_2	.125,000,00	.250,000,00	.375,000,00	.500,000,00	.750,000,00	1.000,000,0
C_1	.007,812,500,0	.031,250,000	.070,312,500	.125,000,00	.281,250,00	.500,000,00
C_2, 1st Term	.000,651,041,67	.005,208,333,3	.017,578,125	.041,666,667	.140,625,00	.333,333,33
C_2, 2nd Term	.125,000,00	.250,000,00	.375,000,00	.500,000,00	.750,000,00	1.000,000,0

MOMENTS AND SHEARS

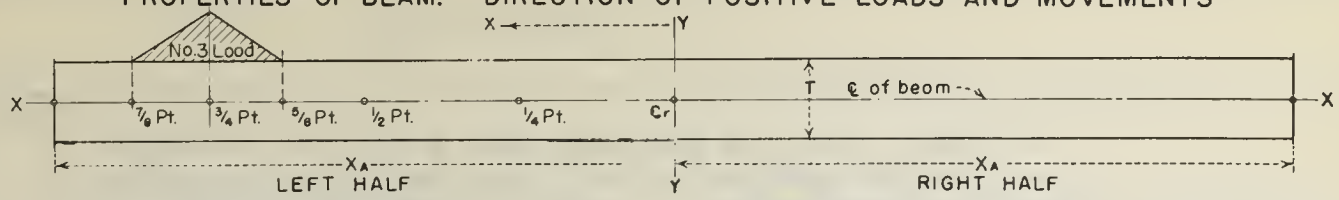
			ABUTMENT	7/8 POINT	3/4 POINT	5/8 POINT	1/2 POINT	1/4 POINT
NORMAL LOADS	1	M_L	2.604,166,7	0	0	0	0	0
		V_L	62.500,000	0	0	0	0	0
	2	M_L	15.625,000	2.604,166,7	0	0	0	0
		V_L	125.000,00	62.500,000	0	0	0	0
	3	M_L	31.250,000	15.625,000	2.604,166,7	0	0	0
		V_L	125.000,00	125.000,00	62.500,000	0	0	0
	4	M_L	46.875,000	31.250,000	15.625,000	2.604,166,7	0	0
		V_L	125.000,00	125.000,00	125.000,00	62.500,000	0	0
	5	M_L	101.562,50	78.125,000	54.687,500	31.250,000	10.416,667	0
		V_L	187.500,00	187.500,00	187.500,00	187.500,00	125.000,00	0
	6	M_L	187.500,00	156.250,00	125.000,00	93.750,000	62.500,000	10.416,667
		V_L	250.000,00	250.000,00	250.000,00	250.000,00	250.000,00	125.000,00
	7	M_L	114.583,33	98.958,333	83.333,333	67.708,333	52.083,333	20.833,333
		V_L	125.000,00	125.000,00	125.000,00	125.000,00	125.000,00	125.000,00
	Σ	M_L	500.000,00	382.812,50	281.250,00	195.312,500	125.000,00	31.250,000
		V_L	1,000.000,0	875.000,00	750.000,00	625.000,00	500.000,00	250.000,00
COUPLE LOADS	1	M_L or $\mathfrak{M}_L$	62.500,00	0	0	0	0	0
	2	M_L or $\mathfrak{M}_L$	125.000,00	62.500,00	0	0	0	0
	3	M_L or $\mathfrak{M}_L$	125.000,00	125.000,00	62.500,00	0	0	0
	4	M_L or $\mathfrak{M}_L$	125.000,00	125.000,00	125.000,00	62.500,00	0	0
	5	M_L or $\mathfrak{M}_L$	187.500,00	187.500,00	187.500,00	187.500,00	125.000,00	0
	6	M_L or $\mathfrak{M}_L$	250.000,00	250.000,00	250.000,00	250.000,00	250.000,00	125.000,00
	7	M_L or $\mathfrak{M}_L$	125.000,00	125.000,00	125.000,00	125.000,00	125.000,00	125.000,00
	Σ	M_L or $\mathfrak{M}_L$	1,000.000,0	875.000,00	750.000,00	625.000,00	500.000,00	250.000,00

LOAD CONSTANTS

			7/8 POINT	3/4 POINT	5/8 POINT	1/2 POINT	1/4 POINT	CROWN
NORMAL LOADS	1	D_1	.081,380,208	.081,380,208	.081,380,208	.081,380,208	.081,380,208	.081,380,208
		D_2, 1st Term	.008,138,020,8	.018,310,547	.028,483,073	.038,655,599	.059,000,651	.079,345,703
		D_2, 2nd Term	2.604,166,7	2.604,166,7	2.604,166,7	2.604,166,7	2.604,166,7	2.604,166,7
	2	D_1	.244,140,62	1.139,322,9	1.139,322,9	1.139,322,9	1.139,322,9	1.139,322,9
		D_2, 1st Term	.022,379,557	.223,795,57	.366,210,93	.508,626,30	.793,457,02	1.078,287,8
		D_2, 2nd Term	5.208,333,3	15.625,000	15.625,000	15.625,000	15.625,000	15.625,000
	3	D_1	0	1.383,463,5	4.069,010,4	4.069,010,4	4.069,010,4	4.069,010,4
		D_2, 1st Term	0	.246,175,13	1.159,668,0	1.668,294,3	2.685,546,9	3.702,799,5
		D_2, 2nd Term	0	13.020,833	31.250,000	31.250,000	31.250,000	31.250,000
	4	D_1	0	0	3.499,349,0	8.951,822,9	8.951,822,9	8.951,822,9
		D_2, 1st Term	0	0	.917,561,85	3.316,243,5	5.554,199,2	7.792,154,9
		D_2, 2nd Term	0	0	20.833,333	46.875,000	46.875,000	46.875,000
	5	D_1	0	0	0	6.591,796,9	28.076,172	28.076,172
		D_2, 1st Term	0	0	0	2.280,680,3	15.777,588	22.796,631
		D_2, 2nd Term	0	0	0	28.645,833	101.562,50	101.562,50
	6	D_1	0	0	0	0	27.994,792	71.614,583
		D_2, 1st Term	0	0	0	0	14.680,990	53.059,896
		D_2, 2nd Term	0	0	0	0	83.333,333	187.500,00
	7	D_1	0	0	0	0	0	52.734,375
		D_2, 1st Term	0	0	0	0	0	36.490,885
		D_2, 2nd Term	0	0	0	0	0	114.583,33
	Σ	D_1	.325,520,83	2.604,166,7	8.789,062,5	20.833,333	70.312,500	166.666,67
		D_2, 1st Term	.030,517,578	.488,281,25	2.471,923,8	7.812,500,0	39.550,781	125.000,00
		D_2, 2nd Term	7.812,500,0	31.250,000	70.312,500	125.000,00	281.250,00	500.000,00
COUPLE LOADS	1	D_1 or D_4	2.604,166,7	2.604,166,7	2.604,166,7	2.604,166,7	2.604,166,7	2.604,166,7
		D_2	.244,140,62	.569,661,46	.895,182,29	1.220,703,1	1.871,744,8	2.522,786,5
	2	D_1 or D_4	5.208,333,3	15.625,000	15.625,000	15.625,000	15.625,000	15.625,000
		D_2	.406,901,04	2.766,927,1	4.720,052,1	6.673,177,1	10.579,427	14.485,677
	3	D_1 or D_4	0	13.020,833	31.250,000	31.250,000	31.250,000	31.250,000
		D_2	0	1.871,744,8	7.649,739,6	11.555,990	19.368,490	27.180,990
	4	D_1 or D_4	0	0	20.833 333	46.875 000	46.875 000	46.875 000
		D_2	0	0	4.313,151,0	14.485,677	26.204,427	37.923,177
	5	D_1 or D_4	0	0	0	28.645,833	101.562,50	101.562,50
		D_2	0	0	0	7.731,119,8	48.095,703	73.486,328
	6	D_1 or D_4	0	0	0	0	83.333,333	187.500,00
		D_2	0	0	0	0	34.505,208	115.885,42
	7	D_1 or D_4	0	0	0	0	0	114.583,33
		D_2	0	0	0	0	0	61.848,958
	Σ	D_1 or D_4	7.812,500,0	31.250,000	70.312,500	125.000,00	281.250,00	500.000,00
		D_2	.651,041,67	5.208,333,3	17.578,125	41.666,667	140.625,00	333.333,33

205-D-1842

PROPERTIES OF BEAM. DIRECTION OF POSITIVE LOADS AND MOVEMENTS



UNIT LOAD DESCRIPTION										
No. 1	P	Units	at	obut.	to	zero	at	7/8 pt.		
No. 2	"	"	"	7/8 pt.	"	"	"	obut.	and	3/4 pt.
No. 3	"	"	"	3/4 pt.	"	"	"	7/8 pt.	"	5/8 pt.
No. 4	"	"	"	5/8 pt.	"	"	"	3/4 pt.	"	1/2 pt.
No. 5	"	"	"	1/2 pt.	"	"	"	5/8 pt.	"	1/4 pt.
No. 6	"	"	"	1/4 pt.	"	"	"	1/2 pt.	"	Cr. pt.
No. 7	"	"	"	Cr. pt.	"	"	"	1/4 pt.	"	

DIRECTION OF APPLIED LOADS (LEFT HALF)	POSITIVE MOVEMENT OF BOTH PARTS		DIRECTION OF APPLIED LOADS (RIGHT HALF)
+ Normal load ↓	ΔY = normal	θ = angular	+ Normal load ↓
+ Direct couple load ↻	↑ (upstream)	↺ (counter-clockwise)	+ Direct couple load ↺

Normal loads are applied at the upstream face.
Direct couple loads are applied at the beam center-line.
Unit direct couple load No.7 on right part of beam has same direction as unit direct couple load No. 7 on left part of beam.

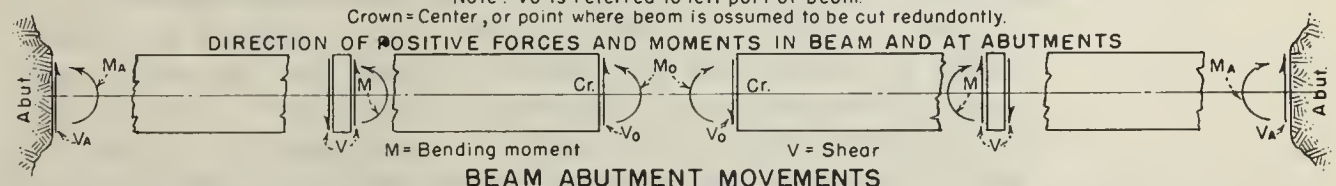
DIRECTION OF POSITIVE FORCES AND MOMENTS. DIRECTION OF FORCES AND MOMENTS DUE TO POSITIVE LOADS

LOAD ON LEFT HALF	DIRECTION OF M_L	DIRECTION OF V_L
Normal	↻	↓
Direct couple	↻	

SUBSCRIPTS
o = Crown of beam.
A = Abutment of beam.
L = External load on left part.
R = External load on right part.
Note: Vo is referred to left part of beam.
Crown = Center, or point where beam is assumed to be cut redundantly.

LOAD ON RIGHT HALF	DIRECTION OF M_R	DIRECTION OF V_R
Normal	↺	↓
Direct couple	↺	

DIRECTION OF POSITIVE FORCES AND MOMENTS IN BEAM AND AT ABUTMENTS



BEAM ABUTMENT MOVEMENTS

α = Angular movement in horizontal plane due to unit horizontal bending moment, M_A.
γ = Normal movement due to unit normal shear, V_A.
α_2 = { Angular movement in horizontal plane due to unit normal shear, V_A ; Normal movement due to unit horizontal bending moment, M_A }

$\alpha = \alpha' \cos^3\psi + \beta' \sin^2\psi \cos\psi$
$\gamma = \gamma' \cos\psi$
$\alpha_2 = \alpha'' \cos^2\psi$

NOTATION

ψ = Angle between canyon wall at beam abutment and the vertical.
α' = Rotation normal to foundation surface due to unit bending moment per unit element. 205-D-1621
γ' = Deformation in plane of foundation surface due to unit shear force per unit element. 205-D-1623
β' = Rotation in plane of foundation surface due to unit twisting moment per unit element. 205-D-1624
α'' = { Rotation normal to foundation surface due to unit shear force per unit element. ; Deformation in plane of foundation surface due to unit bending moment per unit element. } 205-D-1625
a = Average width of developed base of dam.
b = Average length of developed base of dam.
For α', γ', and α'' use ratio b/a For β', use ratio $\frac{b/2}{a}$
μ = Poisson's ratio.
E_R = Modulus of elasticity of foundation material in direct stress.
E_C = Modulus of elasticity of concrete in direct stress.

CONSTANT LOAD BEAM
A_1 = Horizontal angular movement at a point due to unit moment M at that point.
C_1 = Horizontal angular movement at a point due to unit shear V at that point, or = Normal movement at a point due to unit moment M at that point.
C_2 = Normal movement at a point due to unit shear V at that point.
D_1 = Horizontal angular movement at a point due to external load to left of that point'.
D_2 = Normal movement at a point due to external load to left of that point.'
' For external load to left of point for load on left part of beam, and to right of point for load on right part of beam.
M_{L-R}, V_{L-R} = Forces at a point due to external load between point and crown.

EQUATIONS FOR DEFLECTIONS AND ANGULAR MOVEMENTS

θ = Horizontal angular movement[2] of center-line of beam $= A_1 M + C_1 V - D_1$
Δy = Normal movement[2] of center-line of beam $= C_1 M + C_2 V - D_2$
[2] These must include transferred abutment movements which are to be added to the above equations.
Assuming a beam cut at the crown, and considering the part of beam under the load, the crown deflections become:

LOAD ON PART OF BEAM — LEFT

$$ {}_L\theta_o = \left[A_1' \frac{12}{E_C T^3} + \alpha\right] M_o + \left[C_1' \frac{12}{E_C T^3} + \alpha X_A + \alpha_2\right] V_o - \begin{cases} \text{Normal load} \ldots\ldots\ldots\ldots \left(D_1' \frac{12}{E_C T^3} + {}_AM_L \alpha + {}_AV_L \alpha_2\right) \\ \text{Direct couple load} \ldots\ldots \left(D_1' \frac{12}{E_C T^3} + {}_AM_L \alpha\right) \end{cases} $$

$$ {}_L\Delta Y_o = \left[C_1' \frac{12}{E_C T^3} + \alpha X_A + \alpha_2\right] M_o + \left[(C_2' \text{ 1st Term}) \frac{12}{E_C T^3} + (C_2' \text{ 2nd Term}) \frac{3}{E_C T} + \alpha X_A^2 + 2\alpha_2 X_A + \gamma\right] V_o - $$
$$ - \begin{cases} \text{Normal load} \left[(D_2' \text{ 1st Term}) \frac{12}{E_C T^3} + (D_2' \text{ 2nd Term}) \frac{3}{E_C T} + (\alpha X_A + \alpha_2)\, {}_AM_L + (\alpha_2 X_A + \gamma)\, {}_AV_L\right] \\ \text{Direct couple load} \left[D_2' \frac{12}{E_C T^3} + (\alpha X_A + \alpha_2)\, {}_AM_L\right] \end{cases} $$

Use abutment functions and beam and load constants for left part of beam.

RIGHT
${}_R\theta_o$ Multiplier of Mo is negative. Complete term containing D_1 is positive. ${}_R\Delta Y_o$ Multiplier of Vo is negative.
Use R for L, in abutment functions and beam and load constants for right part of beam.

SOLUTION FOR CROWN FORCES — SYMMETRICAL BEAM

By equating the crown deflections of the two parts of the beam and solving the resulting equations of θ_o and ΔY_o, simultaneously, the crown forces, Mo and Vo, required to restore the continuity of the beam at the crown, are evaluated:

$$ M_o = \frac{D_1}{A_1} \quad , \quad V_o = 0 $$

With these crown forces and the external load forces, the forces and deflections at any point of the beam ℄ may be found for any of the unit loads described above.

FORMULAE FOR BEAM AND LOAD CONSTANTS

$A_1' = \int dx$
$C_1' = \int x\,dx$
C_2' 1st Term $= \int x^2 dx$
C_2' 2nd Term $= 3\int dx$
D_1' = Trigonometric part of $\int \frac{M_L dx}{EI}$
D_2' 1st Term = Trigonometric part of $\int \frac{M_L x\,dx}{EI}$
D_2' 2nd Term = Trigonometric part of $3\int \frac{V_L dx}{EI}$

NOTE: For evaluation of beam and load constant formulae, see chapter III, Tech. Memo. No. 570

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TECHNICAL ANALYSIS OF DAMS

NOTATIONS, DEFINITIONS, AND EQUATIONS FOR BEAM ANALYSIS

DRAWN F.A.H.	SUBMITTED		
TRACED O.R.S.	RECOMMENDED		
CHECKED F.D.K.	APPROVED		

REV. 8-2-44

DENVER, COLO., OCT. 15, 1937 — 205-D-1980

(.124F)

constants used in a beam analysis are also given in the notation. Equations for deflections and angular movements are given in general form in terms of beam, load, and abutment constants, and the solution for crown forces M_o and V_o is indicated. Finally, formulas for beam and load constants are presented at the bottom portion of the drawing. The actual evaluation of these constants is given in Figure 39.

RELIEVING TWIST ACTION

.125 Theoretically, twist effects may sometimes be kept within desirable or permissible limits by leaving the construction joints ungrouted or by grouting under partial reservoir load so that some readjustment of deflections can take place at the joints before the structure is made monolithic. Practically, however, such procedure can seldom be recommended. Leaving the joints ungrouted for long periods is undesirable inasmuch as leakage around the seals near the upstream face of the dam may follow through the joints to the downstream face causing an unsightly appearance and even spalling of the concrete if the dam is subjected to alternate freezing and thawing. Furthermore, twist effects in ungrouted structures may be as great as in grouted structures if the reservoir load is applied before the setting heat has been dissipated sufficiently to open the contraction joints. The generation of chemical heat during curing may keep the joint completely closed so that loads may be carried downward to the foundation by torsion in vertical planes and horizontally to the abutments by twist and some bending, as well as vertically to the foundation by cantilever bending and shear.

TWIST SLOTS

.126 Another method to relieve twist action in cases where trial-load analyses show twist effects to be definitely detrimental and of undesirable magnitude, is to provide open twist slots in the abutment sections of the dam. This was done in the case of Grand Coulee Dam. Such slots theoretically constitute definite barriers to the extension of horizontal beam and twist action inasmuch as they eliminate horizontal stress transference as well as permit the relaxing of unequal cantilever deflections on the two sides of the slots. Of course, they must be closed by some special type of slab construction at the upstream face capable of sliding adjustment at one or both seats during the application of the reservoir load. In Grand Coulee Dam, the slots were temporarily filled with sand to prevent settling of the abutment cantilevers toward the central portion of the dam, and to support the cantilevers while the contraction joints were being grouted. Afterward the sand was sluiced out and the

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TWIST SLOTS (CONT.)

slots were permanently closed with concrete. Care should be exercised to allow for the extension of the twist slots, in case they are used, to the foundation. In the construction of Grand Coulee Dam, concrete had been placed in several lifts above the foundation at slot locations before it was decided to incorporate the twist slots in the design of the dam. Subsequent trial-load studies showed the slots to be definite barriers to the extension of twist action, but also indicated dangerous concentrations of twist effects in the concrete at the bases of the twist slots.

NONLINEAR STRESS ANALYSIS BY ANALOGY METHODS

.127 One of the most common simplifying design assumptions is to consider the distribution of normal stress across a section of a structural member to vary as a straight line, whether it be a beam, column, arch, or a cantilever element of a dam. In masonry dam design, it is generally assumed that normal stresses on horizontal sections in a cantilever element of gravity and arch dams, and on vertical sections of arch dams vary linearly from the upstream to the downstream face at all elevations. Although the assumption of uniformly varying stress greatly simplifies the method of analysis for ordinary design information, it may not be sufficiently accurate for determining stresses on sections at or near the base of a high dam. The exact law of nonuniform stress variations is unknown, and any approach toward a determination of true stresses must be made either by experimental means or some analytical solution based on the theory of elasticity.

SLAB ANALYSIS

.128 The so-called "Slab Analysis" method of nonlinear stress investigation was developed in connection with the design of Boulder Dam and is amply described in "Stress Studies for Boulder Dam," Bulletin 4, Part V, of the Boulder Canyon Project Final Reports. Consequently, the method will be only briefly described here. The solution is analytical and made by trial so the analysis is in reality a trial-load procedure. The slab-analysis method is based on the analogy existing between the partial differential equations for an Airy's surface and for the shape of the surface of an homologous slab or plate loaded at the edges. The cantilever section of a masonry dam and a large portion of the foundation considered to act therewith are assumed to be replaced by an analogous slab having the same size and shape as the cantilever and foundation block to be analyzed. Forces existing at the edges of the cantilever and around the boundaries of the foundation block produce moments and couples

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which bend the slab into a shape determined by the boundary loading conditions. The boundary conditions at the bottom and ends of the foundation blocks are determined by the theory of semi-infinite plates, assuming a linear distribution of stress at cantilever base. Saint-Venant's principle states that if the forces acting on a small portion of the surface of an elastic body are replaced by another statically equivalent system of forces acting on the same portion of the surface, this redistribution of loading produces substantial change in the stresses locally, but has a negligible effect on the stresses at distances which are large in comparison with the linear dimension on which the forces are changed. According to this principle, approximations involved by calculating boundary conditions of the foundation blocks on the basis of a linear stress distribution at the cantilever base are overcome by taking a sufficiently large foundation block, and differences which exist between calculated stress distribution and true stress distribution near the edges of the foundation block become negligible over the distance between the cantilever base and edges of the foundation block.

SLAB ANALYSIS (CONT.)

A. As a means toward determining nonlinear stress conditions, the entire slab is divided into two systems of representative beams, one vertical and the other horizontal. Both systems of beams have their ends rigidly fixed at the slab boundaries, but are assumed free to move relative to each other within the boundaries. By applying self-balancing loads and couples along the beam elements, and calculating twists and deflections until the slopes and deformations of the two systems of interior beams are in agreement at conjugate points, the conditions of equilibrium and compatibility of the partial differential equations defining the Airy's surface for the slab are satisfied. Nonlinear stress conditions throughout the entire cantilever and foundation block element may then be determined according to the analogy between the stresses in the dam and curvatures and twists in the slab. Curvatures of horizontal beams represent vertical normal stresses, curvatures of vertical beams represent horizontal normal stresses, and twisting moments of vertical and horizontal beams represent vertical and horizontal shear stresses, respectively.

METHOD OF ANALYSIS

B. The principal notations used in the nonlinear stress analysis are listed below. In the coordinate system,

NOTATION

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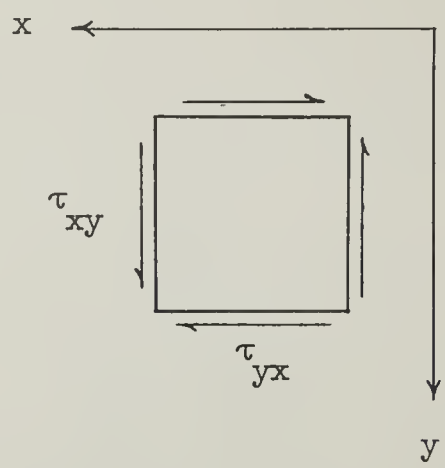
NOTATION (CONT.)

values of x are positive when measured to the left of the origin and values of y are positive when measured downward. A positive slope, integrated in the direction of x or y, gives a positive z deflection. Compressive stresses are considered positive. Positive shearing forces are as shown:



x, y = rectangular coordinates

σ_x = normal stress in the direction of x

σ_y = normal stress in the direction of y

$\tau_{yx} = \tau_{xy}$ = shear on yz- and xy-planes, parallel to x or y

z = deflection of slab normal to the xy-plane

$\frac{\partial z}{\partial x}$ = slope in a plane parallel to the xz-plane

$\frac{\partial z}{\partial y}$ = slope in a plane parallel to the yz-plane

F = Airy's function

μ = Poisson's ratio

E = elastic modulus of slab material

I = moment of inertia per unit width of slab

w_c = unit weight of masonry

w = unit weight of water

M_x, M_y = bending moments per unit width of slab on

(.128B)

planes perpendicular to the x- and y-axes, respectively

NOTATION (CONT.)

M_{xy} = twisting moment per unit width of slab on planes parallel to the xy-plane

K = a proportionality factor between stress in the cantilever and curvature in the slab, which, for convenience, has been made equal to unity

.129 Airy's function, F, which may be represented by a warped surface is given by the equation:

AIRY'S FUNCTION AND THE SLAB ANALOGY

$$\frac{\partial^4 F}{\partial x^4} + \frac{2\partial^4 F}{\partial x^2 \partial y^2} + \frac{\partial^4 F}{\partial y^4} = 0 \qquad \text{..... (16)}$$

The stresses in a two-dimensional weightless structure lying in the xy-plane may be expressed in the form:

$$\sigma_x = \frac{\partial^2 F}{\partial y^2} \qquad \text{.....(17)}$$

$$\sigma_y = \frac{\partial^2 F}{\partial x^2} \qquad \text{..... (18)}$$

$$\tau_{xy} = \frac{\partial^2 F}{\partial x \partial y} \qquad \text{..... (19)}$$

The equations of equilibrium and compatibility for the structure will be satisfied if the stress function, F, of equations (17), (18), and 19 satisfies equation 16. If a homologous elastic slab has its surface parallel to the xy-plane and μ equals zero, moments and twists in the slab may be expressed in terms of the deflection z, measured normal to the surface of the slab, as shown in the following formulas:

$$M_x = EI \frac{\partial^2 z}{\partial x^2} \qquad \text{..... (20)}$$

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AIRY'S FUNCTION AND THE SLAB ANALOGY (CONT.)

$$M_y = EI \frac{\partial^2 z}{\partial y^2} \quad \text{.....} \quad (21)$$

$$M_{xy} = EI \frac{\partial^2 z}{\partial x \, \partial y} \quad \text{.....} \quad (22)$$

Similarly, deflections of an unloaded slab satisfy the partial differential equation

$$\frac{\partial^4 z}{\partial x^4} + \frac{2\partial^4 z}{\partial x^2 \partial y^2} + \frac{\partial^4 z}{\partial y^4} = 0 \quad \text{.....} \quad (23)$$

The identity of form of the partial differential equations of Airy's function, F, and the analogous equations for the homologous slab or plate suggests that the deflection z of the slab may be made to represent the function F, the slab being loaded at its edges only. It is upon this analogy that the so-called "Slab Analysis" method is based, for, if a given differential equation occurs in two different problems, a solution of one of the problems can also be applied as a solution of the other problem. The function, F, and the displacement z will then have the relation:

$$F = KEIz \quad \text{.....} \quad (24)$$

where K is a constant. The quantity KEI may be made equal to unity, thus simplifying the analysis, because these terms do not affect the analogy between the Airy's surface and the stresses in the two-dimensional plate so long as they are kept constant.

ANALOGY RELATIONSHIPS

.130 The equations giving the analogy relationships are as follows:

$$\sigma_x = \frac{\partial^2 F}{\partial y^2} = \frac{\partial^2 z}{\partial y^2} = M_y \quad \text{.....} \quad (25)$$

$$\sigma_y = \frac{\partial^2 F}{\partial x^2} = \frac{\partial^2 z}{\partial x^2} = M_x \quad \text{.....} \quad (26)$$

$$\tau_{xy} = \frac{\partial^2 F}{\partial x \partial y} = \frac{\partial^2 z}{\partial x \partial y} = M_{xy} \quad \text{.....} \quad (27)$$

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That is, any system of curvatures and twists in a slab, warped into a form determined by the forces existing at its boundaries, is analogous to the stress distribution in a prototype having exactly the same shape as the slab and loaded with corresponding boundary forces. The analogy will apply only in case the forces applied around the boundaries of a prototype are such as will hold a two-dimensional rigid body in static equilibrium. Also the slab is assumed to be composed of homogenous, elastic, and isotropic material, as is the prototype itself.

ANALOGY RELATIONSHIPS (CONT.)

.131 Since the weight of the material in a dam is distributed as a force acting on each particle of mass in the structure and not as a boundary load, the analogy cannot be applied directly in an analysis made to determine dead-load stresses in a cantilever and foundation section. However, this discrepancy in analogy requirements for dead-load conditions may be overcome by applying auxiliary load systems which when superimposed, represent actual boundary and weight forces. Fixing the boundaries for an analysis of water-load forces offers no difficulty as the only forces acting on the cantilever and foundation block are those due to horizontal and vertical components of water load. Analysis of inertia and hydrodynamic effects of earthquake shocks may also be handled by the analogy.

ANALOGOUS BOUNDRY LOADS

.132 The analogous slab may be of any dimensions so long as it represents the shape of the prototype under consideration. However, equations of transformation are avoided by analyzing a slab of the same size as the prototype if at every point the slab boundary is given a curvature corresponding to the normal load intensity on the original structure at that point, and a twist corresponding to the like intensity of shear load. A slab so deformed is a physical representation of the stress distribution in the original. By taking Poisson's ratio equal to zero, curvatures and twists may be replaced by equivalent bending and twisting moments as indicated in equations (25), (26), and (27). These bending and twisting moments in the slab are determined by a trial-load process. The slab is considered as divided into systems of representative horizontal and vertical beams, each occupying the full volume of the slab. Continuity requires that slopes and deflections of both systems be equal throughout the slab. The beams, however, are rigidly fastened to the slab boundary and hence are given boundary slopes and deflections at the ends. At this stage, the two systems are not coincident.

OPERATIONS

(.132)

OPERATIONS (CONT.)

Differences of slopes and deflections are corrected by applying equal and opposite loads to the two systems at each beam intersection. Use of a system of unit loads applied at intersection points has been found to expedite computations. Loads are varied by trial until equality of slopes and deflections is obtained at all intersections. The operation is accomplished in two adjustments, the twist or slope adjustment and the deflection adjustment. When a satisfactory adjustment is secured, normal and shearing stresses are computed from the total bending and twisting moments on the beams.

NONLINEAR STRESS EFFECTS

.133 Nonlinear stress investigations have been made on three of our largest and most important dams, Boulder, Grand Coulee, and Shasta. Conclusions drawn from several studies made for maximum cantilever sections of these dams are that stresses computed using the gravity analysis are generally increased in the vicinity of the upstream and downstream edges of the base by amounts that warrant consideration in design. Also, nonlinear stress distribution may vary considerably from the linear assumption at and near the base but the nonlinear distribution rapidly approaches that of the linear law within approximately one-third the height of the cantilever above the base.

MAXIMUM EFFECTS

.134 The maximum nonlinear stress effects which occur in the vicinity of the bases of the above-named dams are shown in Figure 41. The table shows comparison between stresses based on linear and nonlinear distribution for the vertical, horizontal, and shear stresses in the regions of the upstream and downstream toes. Since the slab analysis method bears out the proof by the theory of elasticity that the theoretical maximum shear stresses are infinite at the reentrant corners of the base, the values given are for the maximum computed shear stresses at conjugate beam points nearest the corners. The most important changes in stress are in vertical stresses, so far as the design of the section is concerned. The maximum increase in vertical upstream stress is shown for the case of Boulder Dam, with an 18 percent increase. The maximum vertical effect at the downstream toe is a 64 percent increase for the case of the maximum nonoverflow section of Grand Coulee Dam. The studies of sections of Shasta Dam showed the least departure of stresses from the linear law of any nonlinear studies completed to date. Here the upstream vertical stresses were decreased by approximately 12 percent and the downstream

TABLE II

MAXIMUM NONLINEAR STRESS EFFECTS IN SECTIONS OF VARIOUS DAMS

Dam	BOULDER	GRAND COULEE		SHASTA		
Cantilever Section	Crown	Maximum Non-Overflow	Maximum Spillway With Bucket	Maximum Non-Overflow	Maximum Spillway	Maximum Non-Overflow
Loading Condition	Dead Load plus Trial Load† Water Load	Dead Load plus Full Water Load	Dead Load plus Full Water Load	Dead Load plus Full Water Load	Dead Load plus Full Water Load	Dead Load plus Full Water Load plus Earthquake
Region near Upstream Edge of Base						
Maximum Change, vertical normal stress	555 to 654	261 to 302	245 to 260	227 to 204	239 to 172	155 to 111
Maximum Change, horizontal normal stress	230 to 405	221 to 72	198 to 194	200 to 120	219 to 48	198 to 54
Maximum Change, shear stress*	68 to 32	0 to 160	5 to 95	-15 to -48	-9 to -72	36 to 73
Region near Downstream Edge of Base						
Maximum Change, vertical normal stress	271 to 377	332 to 546	289 to 196	248 to 282	339 to 371	356 to 397
Maximum Change, horizontal normal stress	139 to 299	226 to 406	184 to 369	179 to 256	199 to 310	222 to 317
Maximum Change, shear stress*	140 to 120	190 to 216	195 to 240	213 to 297	240 to 109	271 to 318

Notes:

† Based on trial load arch dam analysis.

* Theoretical maximum shear is infinite at reentrant corner; therefore value given is the maximum computed stress in vicinity of corner.

Figures to left based on gravity stress analysis; figures to right based on nonlinear stress analysis.

FIG. 41 par. 5.2.134

(.134)
stresses increased by corresponding amounts. Since the batter of the upstream face at the base of the cantilever is 0.5, which would allow for a better introduction of stresses from the dam into the foundation than from a sharper reentrant, it is believed that this factor is responsible for the closer agreement in stresses. The table shows that horizontal stresses may be increased over twice their values by the ordinary linear assumption. This is an important consideration in the design of gallery and drainage systems, outlet works, power penstocks, elevator shafts, and other openings in the dams. The studies show that shear stresses follow rather closely the parabolic distribution obtained by an ordinary gravity analysis, except of course, at the reentrant corners.

MAXIMUM EFFECTS (CONT.)

.135 Many of the two-dimensional problems encountered in engineering are difficult or impossible of solution when treated mathematically. Necessity has fostered the approximate lattice-analogy method of dealing with such problems. This section will describe the method and some of its applications rather than the derivation of formulas involved in its usage. As far as practical engineering problems are concerned, the field of application is restricted only by two limitations: the shape of the section must be such that it can be built up, exactly or to a satisfactory approximation, from a limited number of square elements, and the value of Poisson's ratio must be one-third. The limitation upon Poisson's ratio is usually unimportant. In many cases, stress distribution is independent of the values of the elastic constants, and in cases where these constants affect the results, the value of one-third will ordinarily be close enough to the true value that only small differences will exist in stresses or displacements.

LATTICE ANALOGY

.136 As in the usual treatment of two-dimensional problems in elasticity, a section of the structure to be analyzed is considered as though it were a slice or plate of unit thickness, in accordance with the generalized theory of plane stress. The plate is simulated in size and shape by a lattice network composed of interconnected elemental square frames, each diagonally connected at the corners. When the plate has irregular boundaries, its outline may be approximated to any desired degree of accuracy depending on the number of frames chosen. As the number is increased, however, the solution becomes more involved so that for any problem a practical decision must be made as to the refinement desired. The validity of the

GENERAL DESCRIPTION OF METHOD

(.136)

GENERAL DESCRIPTION OF METHOD (CONT.)

simulation may be shown by demonstrating that in the limit, as the dimensions of the square frames approach zero, the differential equations of equilibrium and compatibility become identical for the lattice and the plate, and the boundary conditions become expressible in the same form. Thus the two solutions become identical and for obvious reasons the lattice is referred to as analogous to the plate.

CONDITIONS TO BE SATISFIED FOR ANALOGY

A. In the analogy between the lattice and the plate, three fundamental conditions must be satisfied in order that an assemblage of elemental lattices may constitute a plate. These conditions are:

(1) The normal and tangential stresses must be distributed throughout the plate in such a way that the forces acting upon each element are in equilibrium with respect to translation and rotation of the element.

(2) The extensions and detrusions of the elements resulting from these stresses constitute a single-valued system of displacements.

(3) Any special conditions of stress or displacement which are specified at the boundaries must be satisfied.

SOLUTION BY PROGRESSIVE RELAXATION

B. Having replaced the plate prototype by a lattice framework, a solution may be devised for the lattice and applied to the plate. The essential concept involved in this solution is a systematic relaxation of restraints at the joints. A description of a relaxing process to aid in an understanding of the adjustment will be given subsequently. After the adjustment of the lattice to remove restraint has been completed, the strains are deduced from relative displacements between successive joints and from these the stresses may be computed.

SOLUTION OF THE LATTICE

C. The fundamental device employed in the lattice analogy is the elemental square frame which is composed of six elastic members, two of which are horizontal, two vertical, and two diagonal. The length of the sides is considered unity in the derivation of the lattice formulas. The six members are assumed to be connected at the corners by frictionless joints. The elastic properties of the frame members are determined so that the

(.136C)

behavior of the frame under given boundary conditions will correspond exactly to the square element of the plate section with respect to axial elongation, lateral contraction, and shear detrusion. In a lattice network composed of many frames, the amount of work involved in a conventional solution would be tremendous. However, by using a relaxation method, one may deal with a small region in which equilibrium is easily established and the method can consequently be applied to intricate lattice systems. Adjustment of equilibrium in a second region disturbs the first, but still leaves it approaching final equilibrium. The operations of adjustment are easily applied when each step is confined to a single joint.

SOLUTION OF THE LATTICE (CONT.)

D. To illustrate the method, consider the simplest case where the boundary conditions are given in terms of displacements. The procedure of adjustment may be visualized as follows: Consider a lattice actually constructed to a given scale, with elastic members coming together at the corners to form frictionless hinged joints. Lay this lattice out on a horizontal board, and before applying any displacements, completely restrain all joints by nailing them to the board. Next, displace and secure again, the various boundary joints through distances corresponding to their assigned displacements. Then, working in a line of joints adjacent to a displaced boundary, free one joint and allow it to move to a new position of equilibrium and resecure it. Repeat the process at successive joints until all have been adjusted (keeping only the boundary joints fixed in conformity with the given displacements) as many times as is required to give a satisfactory approach to the condition of complete transfer of forces from the interior nails to the members of the lattice. Simple relationships then exist between displacements and stresses.

PHYSICAL ILLUSTRATION OF METHOD

.137 Lattice equations for the displacement of an interior joint, an exterior corner joint, reentrant corner joint, and a boundary joint have been developed in terms of loads at the joint and in terms of displacement of the surrounding joints. These equations are shown in Figure 42.

LATTICE EQUATIONS

.138 Boundary conditions for the problem can be given either in loadings or in displacements. For the design of

BOUNDARY CONDITIONS

(.138)

structures, estimated or computed loads would probably comprise the boundary conditions, but for structures already built it is more likely that boundary conditions would be given in terms of measured displacements. In either case, the loads or displacements for the plate must be expressed in terms of loads or displacements for the boundary joints of the lattice. However, the adjustment of the lattice is always made by adjusting displacements at the interior joints to remove restraints.

DETERMINATION OF STRESSES

.139 Normally, the purpose of computing a lattice would be to determine stresses in the prototype. The adjustment of the lattice to remove restraint having been completed, the resulting displacements may be applied to the plate. The difference of displacements between successive lattice joints will yield strains, and stresses may be computed from the conventional stress—strain relationship.

RESTRAINING FORCES

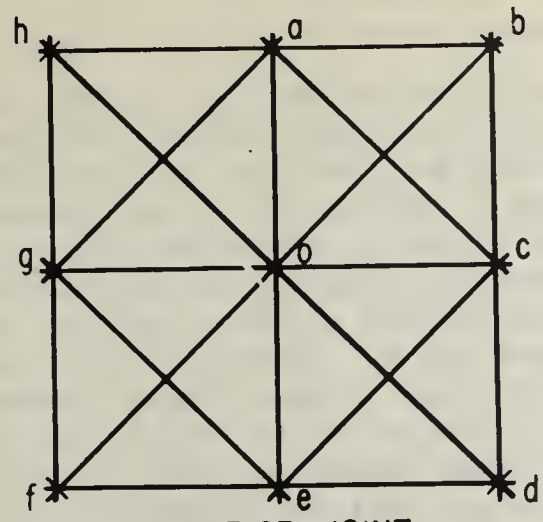
A. At any time during adjustment of a lattice, the restraining forces at the joints may be computed. For an exact solution, these forces will reduce to zero, and they are, therefore, a measure of the accuracy of the adjustment at any stage. Ordinarily, the computation of the restraining forces involves considerable work so that other methods are used to judge the end of an adjustment. The easiest way is to over-adjust the displacements so that reversal occurs in their direction because of passing the end point.

BODY FORCES

B. The equations previously mentioned concerning displacement at certain joints due to loads at these joints, will apply to the body forces of the structure. Such loads can be introduced into the lattice adjustment by computing the horizontal and vertical components, computing the displacements and adding these displacements to those produced by displacements of the surrounding joints. Certain limited types of body forces, including gravity forces, may also be handled by Biot's method of applying fictitious boundary pressures.

THERMAL STRESSES

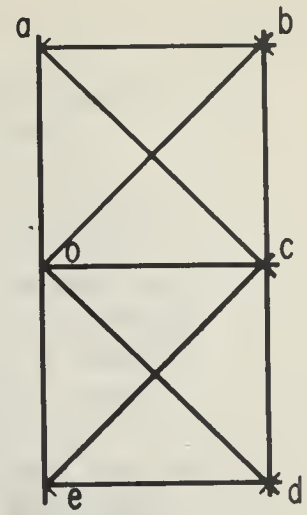
C. A system has been devised in which displacements due to temperature change are computed by the application of fictitious body and boundary forces. The determination of the fictitious forces is somewhat involved and will not be given here, and the application of body and boundary forces to a lattice system has already been discussed.



INTERIOR JOINT

$$h_o=\frac{4}{9E}H_o+\frac{1}{12}(h_b+v_b+4h_c+h_d-v_d+h_f+v_f+4h_g+h_h-V_h)$$

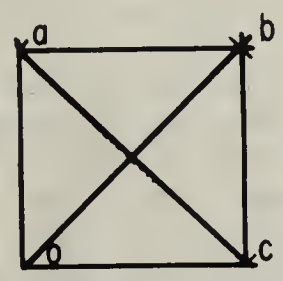
$$V_o=\frac{4}{9E}V_o+\frac{1}{12}(4v_a+h_b+v_b-h_d+v_d+4v_e+h_f+v_f-h_h+v_h)$$



BOUNDARY JOINT

$$h_o=\frac{8}{9E}H_o+\frac{1}{6}(h_b+v_b+4h_c+h_d-v_d)$$

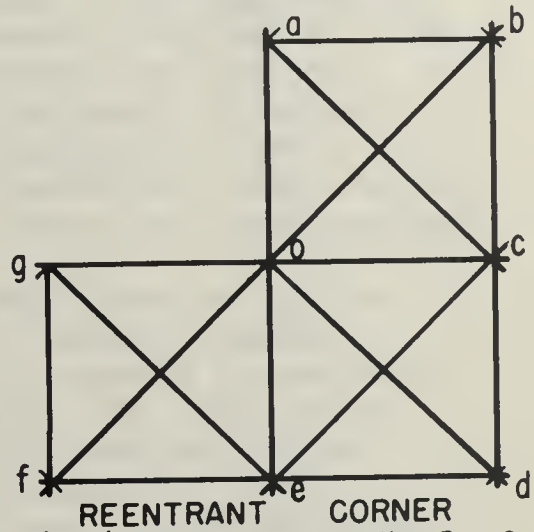
$$V_o=\frac{8}{9E}V_o+\frac{1}{6}(2v_a+h_b+v_b-h_d+v_d+2v_e)$$



EXTERIOR CORNER

$$h_o=\frac{2}{3E}(3H_o-V_o)+\frac{1}{4}(-v_a+h_b+v_b+3h_c)$$

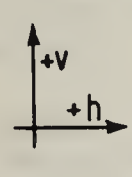
$$V_o=\frac{2}{3E}(3v_o-H_o)+\frac{1}{4}(3v_a+h_b+v_b-h_c)$$



REENTRANT CORNER

$$h_o=\frac{3}{5E}(H_o-\frac{1}{9}V_o)+\frac{1}{40}(-v_a+4h_b+4v_b+18h_c+5h_d-5v_d-2v_e+4h_f+4v_f+9h_g)$$

$$V_o=\frac{3}{5E}(V_o-\frac{1}{9}H_o)+\frac{1}{40}(9v_a+4h_b+4v_b-2h_c-5h_d+5v_d+18v_e+4h_f+4v_f-h_g)$$



h,v indicate displacements of joint O.

H,V indicate forces per unit thickness at O representing body forces at O in plane of lattice.

E is elastic modulus of prototype material.

UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION		
LATTICE ANALOGY EQUATIONS FOR DISPLACEMENTS OF JOINT O		
BY	J.A.H.	JUNE 25, 1946
APV.	C.R.	MD-DT-10

.140 The lattice analogy method of solving two-dimensional nonlinear stress problems in engineering has many applications that are involved in the design of masonry dams. The method is adaptable to the computation of stresses in a gravity dam. A section from a gravity dam is normally computed of unit thickness and its outline could be approximated by a lattice network made up of squares. As has been pointed out, boundary forces (water loads), body forces (dead loads), and thermal forces cause no particular difficulty in adjusting lattice displacements. The principal limitations placed on the applications to gravity dam design or other purposes are the time and labor involved in the calculations. The method has been found useful in determining the stress distribution in a body composed of two or more different materials. This represents a problem of great practical importance, especially in the design of reinforced-concrete structures. Another problem which is fundamental in the study of concrete structures is that of uniform shrinkage of a two-dimensional section on a rigid foundation. This problem has been analyzed successfully, using the lattice analogy.

APPLICATIONS AND LIMITATIONS

.141 The use of models is a very valuable addition to the methods of analysis and design of dams and similar structures of great size requiring careful development and checking of theory. All models come under one of two major classifications: similar models, or those that resemble the prototype, and dissimilar models. Principal among the former group are the two-dimensional and three-dimensional types of elastic displacement models, photoelastic models, and models used in studies employing the slab analogy. In the dissimilar group are those employing such analogies as the membrane, electric, and sand-heap analogies. These last-mentioned types, while of considerable value to stress studies of special problems, do not concern us here, and it is only those model types which have proved adaptable to experimental studies of masonry dam structures that will be discussed here.

ANALYSIS BY EXPERIMENTS

.142 Three-dimensional displacement models are those constructed of elastic materials to proportionate size and loading of the prototype so that deformation, structural action, and stress conditions of the latter can be predicted by measurement of displacements of the model.

THREE-DIMENTIONAL DISPLACEMENTS MODELS

A. The following conditions must be fulfilled, in order to obtain similarity between a model and its

THEORY AND LIMITATIONS

(.142A)

THEORY AND LIMITATIONS (CONT.)

prototype, while at the same time satisfying theoretical considerations and the requirements of practical laboratory procedure.

(1) The model must be a true scalar representation of the prototype.

(2) The loading of the model must be proportional to the loading of the prototype.

(3) Upon application of load, resulting strains and deflections must be susceptible of measurement with available laboratory equipment. Because of reduced scale this condition ordinarily requires a higher specific gravity and greatly reduced stiffness in the model compared to the prototype.

(4) Because of influence of volume strains on the stress distribution, Poisson's ratio should be the same for model and prototype.

(5) The model material must be homogeneous, isotropic, and obey Hooke's law within the working stress limits, since these conditions are assumed to exist in a monolith such as a concrete dam.

(6) Foundations and abutments must be sufficiently extensive to allow freedom for the model to deform in a manner similar to the prototype.

(7) If effects of both live load and gravity forces are to be investigated, the ratio of dead weight to live load should be the same in both model and prototype. If the effects of live load only are to be investigated, the results are not affected by the specific gravity of the model, providing Hooke's law is obeyed and nc cracking occurs.

If all requirements of similarity are fulfilled, the relations between model and prototype may be expressed in simple mathematical terms of ratios. Overall compliance with this restriction is not always possible in model tests of masonry dams, but since the purpose of many tests made on dam models, such as the Boulder Dam model tests described subsequently, is to obtain data for verifying analytical methods of analysis, some variation from true similarity does not detract greatly from the value of the test.

(.142)

B. A one-twelfth scale model of the Stevenson Creek Test Dam, a thin arch dam, was constructed and tested in 1927. Concrete used in the model was mixed from the same aggregate as in the dam. Mercury was used to produce water-load effects. Strain and deflection measurements taken on the model showed close agreement with similar measurements taken on the prototype. Although such an opportunity of making this direct check rarely exists, it was possible in the above case because the prototype had been built primarily, as its name implies, to permit accurate observations of arch dam action under actual service conditions. From the Stevenson Creek Dam test the following important conclusions were drawn:

STEVENSON CREEK DAM MODEL TESTS

(1) A properly constructed small-scale model can be relied on to produce strains and deformations similar to its prototype.

(2) The trial-load method of analysis gives accurate results for a thin arch dam.

C. Model tests of the Gibson Dam were next conducted to obtain data on the action of the type of arch dam in which a considerable portion of the load is carried by gravity action. The Gibson Dam model was built of concrete at a scale of 1 to 68, and loaded and tested in the same manner as the Stevenson Creek Dam model, with the addition of temperature tests and the introduction of refinements to include the effects of tangential shear and twist. The behavior of the Gibson model was entirely satisfactory, and the measured deformations showed excellent agreement with those calculated by the trial-load method.

GIBSON DAM MODEL TESTS

D. Model tests made on Boulder Dam, while largely following the pattern of the Stevenson Creek Dam and Gibson Dam model tests, are particularly notable because of the additional problems presented by the unusual proportions of the prototype. Because of its thick cantilevers, and relatively short arches, it was evident that a concrete model would be too rigid to provide measurable deflections under a mercury load. Consequently, after extensive investigation of materials, two complete models were constructed, representing two designs for Boulder Dam; the first was a plaster-celite model at 1 to

BOULDER DAM MODEL TESTS

(.142D)

BOULDER DAM MODEL TESTS (CONT.)

240 scale, and the second, built later, was of rubber-litharge material at a 1 to 180 scale. The plaster model possessed much superior elastic properties, but the rubber model, while violating similarity requirements, simplified loading and similar laboratory problems. Stresses and deformations in both models were determined experimentally, and analytically by the trial-load method. Comparison of measured and analytically determined values from the plaster model showed very good agreement, particularly in deflection, which constituted a very satisfactory check on the trial-load method of analysis. It also disclosed stress concentrations near the abutments at the top of the dam, where arch lengths changed rapidly. Fillets were added to remedy this effect in a revised design from which the rubber model was copied. Comparison of experimental and analytical values for the rubber model showed greater discrepancies than those for the plaster model, a condition that was expected, inasmuch as the rubber model had greatly different values of elastic modulus along each axis and of Poisson's ratios along each side of three mutually perpendicular planes. Despite this condition of anisotropy, and the additional shortcoming of deforming excessively under load, it was possible to obtain satisfactory agreement between measured and analytical values of stress and deflection by adjusting the observed elastic constants of the rubber model material and including them in the trial-load analysis, thus further proving the versatility of the trial-load analysis.

TWO-DIMENSIONAL DISPLACEMENT MODELS

.143 Two-dimensional displacement models are often referred to as cross-sectional or slab models. Acting under two-dimensional stress such a model can be compared directly only to a similar slice through the prototype acting as a separate stressed member, since in the actual structure all interior points are under three-dimensional stress. The model slab having no forces applied normal to the section, is considered to be in a state of plane stress. A cross-sectional element or cantilever acting as an integral part of a masonry dam is stressed by a more complex system of forces, and is under neither plane stress nor plane strain. A state of plane strain is closely approached, however, in the central cantilever element in a long straight gravity dam and also by a vertical slice through the foundation under the crown cantilever of an arch dam. Assuming a state of plane strain can be realized, similarity of stress and strain

(.143)

can be had if Poisson's ratio is the same for model and prototype. For fairly reliable results in the evaluation of stress distribution in the cantilever section of a dam, the usefulness of the two-dimensional model is limited to the straight gravity type of dam, and then only when applied to the central cantilever element. This usefulness is further limited in its application to arch dam cantilevers, to the immediate neighborhood of the base of the crown cantilever, and to that part of the foundation slab contiguous with it. Two-dimensional arch models, while usually failing to give stress and deformation values which can be taken as representative of those occurring in the prototype, have furnished valuable information in connection with the evaluation of abutment rotation and deformation for use in analytical studies.

TWO-DIMENSIONAL DISPLACEMENT MODEL (CONT.)

.144 Photoelastic models are used extensively by the Bureau for design and analysis of localized portions of masonry dams and their appurtenant works. Stresses in photoelastic models are determined by means of the visible optical effects which are produced by passing polarized light through the model while it is under load. The model material must be elastic, transparent, isotropic, and free from initial or residual stresses. Bakelite, celluloid, gelatin, and glass have been successfully used. Studies employing photoelastic models are usually limited to plane stress or strain, and may be said to have their most important application in the determination of regions of stress concentrations.

PHOTOELASTIC MODELS

.145 Effects of stress in a photoelastic model are made visible by means of an optical instrument known as the photoelastic polariscope. Through a system of polaroids, the polariscope directs a beam of light through the model so polarized that when the material of the model becomes doubly-refractive under stress, the familiar photoelastic pattern is projected to the observer on a screen or photographic plate. The alternate color bands of the pattern, or fringes as they are called, furnish a means of measuring the stress quantity, by a known relation between principal stresses and their retardative effect on polarized light waves passing through the stressed model. This "unit" of measure, called material fringe value, is readily evaluated in the laboratory. For bakelite, the most extensively used material, the value is 87 pounds per square inch per inch of thickness, and represents the stress corresponding to one fringe. Values for any number of fringes, or fringe order, are

USE OF POLARISCOPE

(.145)
found by direct proportion, and by applying a suitable factor of proportionality, corresponding values of the stress quantity in the prototype structure may be determined. This stress quantity is the difference of principal stresses at any point (twice the maximum shear stress), and has particular significance along free boundaries, where one of the principal stresses is zero.

PHOTOELASTIC DETERMINATION OF STRESSES WITHIN A BOUNDARY

.146 Where it is desirable to know the magnitude and direction of the individual principal stresses acting at a point within the model, optical instruments such as the photoelastic interferometer, or the Babinet compensator, are used. The determination of stress from photoelastic models and the techniques used in this type of investigation are subjects too complex to properly come within the scope of this Handbook. The reader is referred to standard works on the subject, such as: Max Frocht's Photoelasticity, Wiley, 1941.

PHOTO-ELASTICITY APPLIED TO STUDY OF DAMS

.147 Much valuable information has been obtained through photoelastic studies in connection with stress distribution and magnitude in dam and foundation structures. The photoelastic studies made on Shasta Dam furnish a good example of the application of the method. These studies were to determine what effects would be produced on dam and foundation stresses by several weak-rock conditions which had been exposed in the foundation during the excavation for construction. A 5-foot clay-filled fault seam was discovered lying in a direction making an approximate 60-degree angle with the proposed axis of the dam. It was desired to determine the depth, if any, to which the seam in question should be excavated and backfilled with concrete in order to keep stresses within allowable limits. Because of the direction of the seam with respect to the dam, three possible locations of the seam were assumed for the tests. Photographs of the photoelastic stress patterns were taken of models constructed and loaded to represent the critical cantilever section under full reservoir load with the fault seam at three alternate locations and at varying depths under the cantilever. These stress patterns were studied with regard to the effect of the various depths of seam repair on the stress at the downstream toe fillet, where the most critical stress condition existed. Figure 43 is a sample of the photoelastic photographs studied. Figure 44 gives curves showing the relation between the values of downstream toe fillet stresses obtained from the photoelastic stress

(.147)
patterns, and the depth of the 5-foot clay-filled fault seam. The foundation treatment shown in Figure 6 was the result of this and other related studies.

.148 In 1932, a series of tests was begun on rubber slab models of the crown cantilever and an arch section of a tentative design of Boulder Dam using the slab analogy proposed by Westergaard.

SLAB ANALOGY EXPERIMENTS

A. In employing the analogy, an adaptation of Airy's two-dimensional stress function was used in establishing boundary conditions which were approximated for the rubber slab models. Briefly, the method is based on the fact that Airy's function governing the distribution of biaxial stresses has the same form as the partial differential equation governing the deflection of a two-dimensional plate or slab loaded at its edges. Accordingly, the method consists of obtaining similarity relationships for shape, principal dimensions, and foundation deformations between a prototype and a thin, homogeneous, and isotropic slab model thereof; and deflecting the slab so that the deflection is everywhere proportional to Airy's function for the particular state of stress. By the analogy, stresses in the prototype are analogous to curvatures in the slab. The loading of the slab takes the form of calculated curvatures and twists which are applied by means of clamps to the boundary. In practice, in order to increase the accuracy, a general method has been established of making the curvatures of the slab represent the difference between the true stresses and an approximate stress distribution which can be represented by a simple mathematical expression.

GENERAL DESCRIPTION OF METHOD

B. Model tests employing the slab analogy, conducted by the Bureau as part of the Boulder Dam experimental program, produced stress curves which checked quite well with other methods of analysis. Whereas the method offered valuable verification of other analytical methods, it is not believed to be as versatile as the better-established slab analysis analytical method or the photoelastic experimental methods.

BOULDER DAM EXPERIMENTS

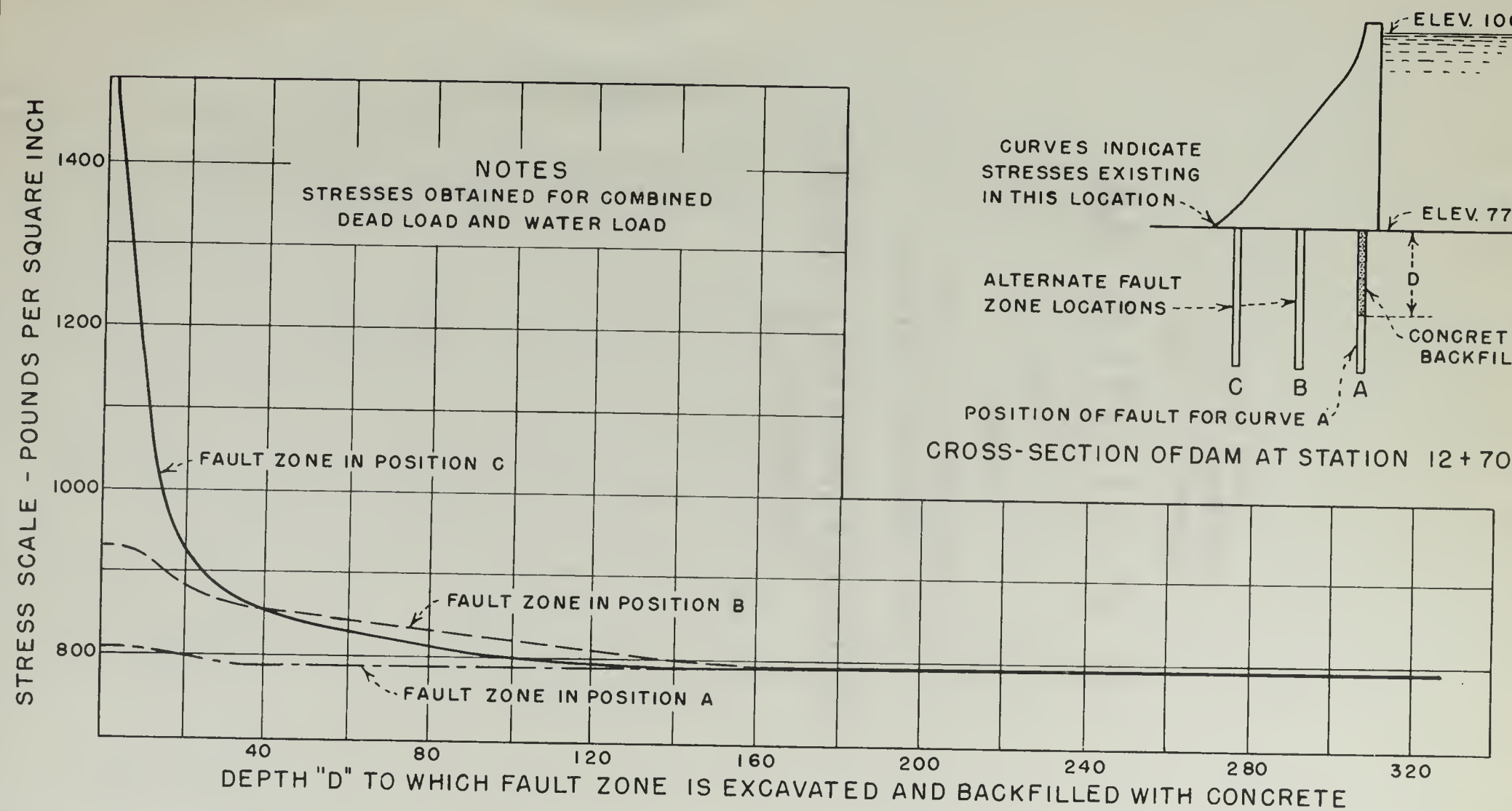
FIG. 43 par. 5.2.147

FAULT SEAM UNDISTURBED

FAULT SEAM EXCAVATED, BACKFILLED 52 FEET

SHASTA DAM

PHOTOELASTIC STUDY OF FOUNDATION FAULT SEAM NEAR DOWNSTREAM FACE – RESERVOIR FULL



SHASTA DAM

PHOTOELASTIC STUDY OF FOUNDATION

RELATION OF STRESS AT TOE TO DEPTH AND LOCATION OF FAULT ZONE

FIG. 44 par. 5.2.147

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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

MANUAL

VOLUME III

PART 5: STORAGE DAMS
CHAPTER 4: BUTTRESS DAMS

DESIGN AND CONSTRUCTION HANDBOOK

Reclamation Manual

VOLUME III--DESIGN AND CONSTRUCTION

PART 5--STORAGE DAMS

CHAPTER 4--BUTTRESS DAMS

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BUTTRESS DAMS 5.4

.1 A buttress dam consists of two principal structural elements: the sloping, water-supporting, upstream face, or deck; and the buttresses that support the deck. The buttresses are vertical walls at right angles to the axis of the dam. The water-supporting deck rests on the sloping upstream edge of the buttresses and its load is transmitted through the buttresses to the foundation. The distinguishing feature of each of the principal types of buttress dams is the kind of water-supporting member carried by the buttresses. Each section of this member, which spans the distance between adjacent buttresses, may consist of a flat slab, an arch, or massive enlargements of the upstream edges of the buttresses themselves which contact each other in a watertight joint midway between the buttresses. Figure 1 shows the relationship of principal structural elements of different types of buttress dams. Buttress dams are usually constructed of reinforced-concrete and description herein will be limited to this type of construction. GENERAL CHARACTERISTICS

A. Due to its hollow construction, a buttress dam requires less material and is therefore much lighter in weight than a massive dam of equal height. This fact may permit its use on foundations which are too weak to support a massive dam. WEIGHT REDUCTION

B. Buttresses may be solid or hollow. The solid or single-wall buttress is usually preferable for use with the massive-head deck and is commonly used in flat-slab and multiple-arch dams. The hollow or double-wall buttress is most often used in multiple-arch dams. TYPES OF BUTTRESSES

C. Secondary structural elements of buttress dams include footings, stiffeners or lateral bracing between buttresses, corbels or other means of transferring the water load from the deck to the buttresses, cut-off walls, grout curtains, and others. SECONDARY ELEMENTS

.2 Types of buttress dams include the following: TYPES OF BUTTRESS DAMS

A. As the name implies, the distinguishing feature of the flat-slab type of dam is the flat-slab water-supporting deck. The deck is built in sections, each section spanning the distance between adjacent buttresses. The slabs are supported by corbels or haunches on the sloping upstream edges of the buttresses. To provide watertight expansion joints and to obtain flexibility through articulation, the surfaces of the corbels and buttress tongues that FLAT-SLAB TYPE

(.2A)

FLAT-SLAB TYPE (CONT.)

contact the slabs are coated with an asphalt or mastic filler. Figure 1, section A-A, shows a section through typical joints. Articulation is desired in order to provide sufficient flexibility for the deck to conform to slight unequal settling of the buttresses.

Stony Gorge Dam in California and Thief Valley Dam in Oregon are examples of the flat-slab type. Figure 2 contains photographs of these dams. Both dams have overflow spillway sections.

MULTIPLE-ARCH TYPE

B. The water-supporting member of the multiple-arch dam consists of a series of arches, each of which spans the distance between adjacent buttresses. Figure 3 shows photographs of Bartlett Dam in Arizona, a notable example of this type. In some dams, the walls of the hollow buttresses are continuous with the arches as shown in Figure 1, section C-C. Figure 4 shows how corbels or haunches may be used to transfer the water load from the arch deck to a single-wall buttress. Where hollow buttresses are used, the space between walls is closed by a flat slab on the upstream edge.

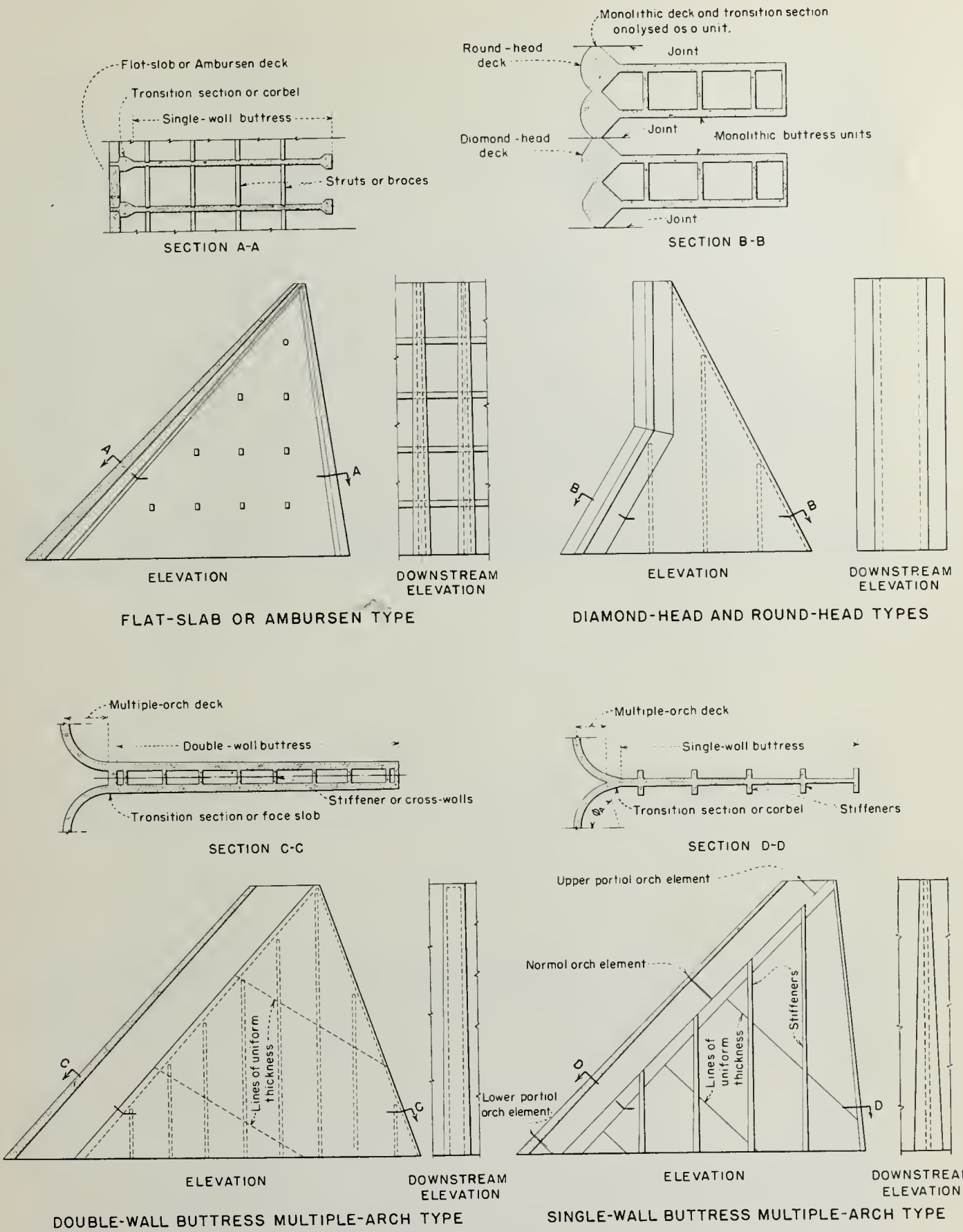
MASSIVE-HEAD TYPE

C. The massive-head type of buttress dam is characterized by flaring of the upstream edges of the buttresses, forming a water-supporting deck. A sectional view of this type of dam is shown in Figure 1, section B-B. To secure watertightness, a flashing and key are provided at the joint between the heads, as the enlargements are called. This type of construction offers the advantages of mass-concrete methods, and compressive stresses throughout the deck. The introduction of the idea is comparatively recent and only a few designs have reached the construction stage. No massive-head dams have been built in the United States, but several have been built in other countries.

OTHER TYPES

D. The truss-buttress and the columnar-buttress types of dams are modifications of the flat-slab type. They are types characterized by reinforced-concrete trusses or a series of inclined columns of reinforced-concrete replacing each of the conventional solid buttresses. Few of them exist because of their requirement for exceptionally good rock foundation and because very little, if any, saving in cost over conventional types can be realized. The multiple-dome type of buttress

FIG. 1 par. 5.4.1



Combinations of component parts are shown for illustrative purposes only. Proper combination depends upon design conditions. Footings not shown.

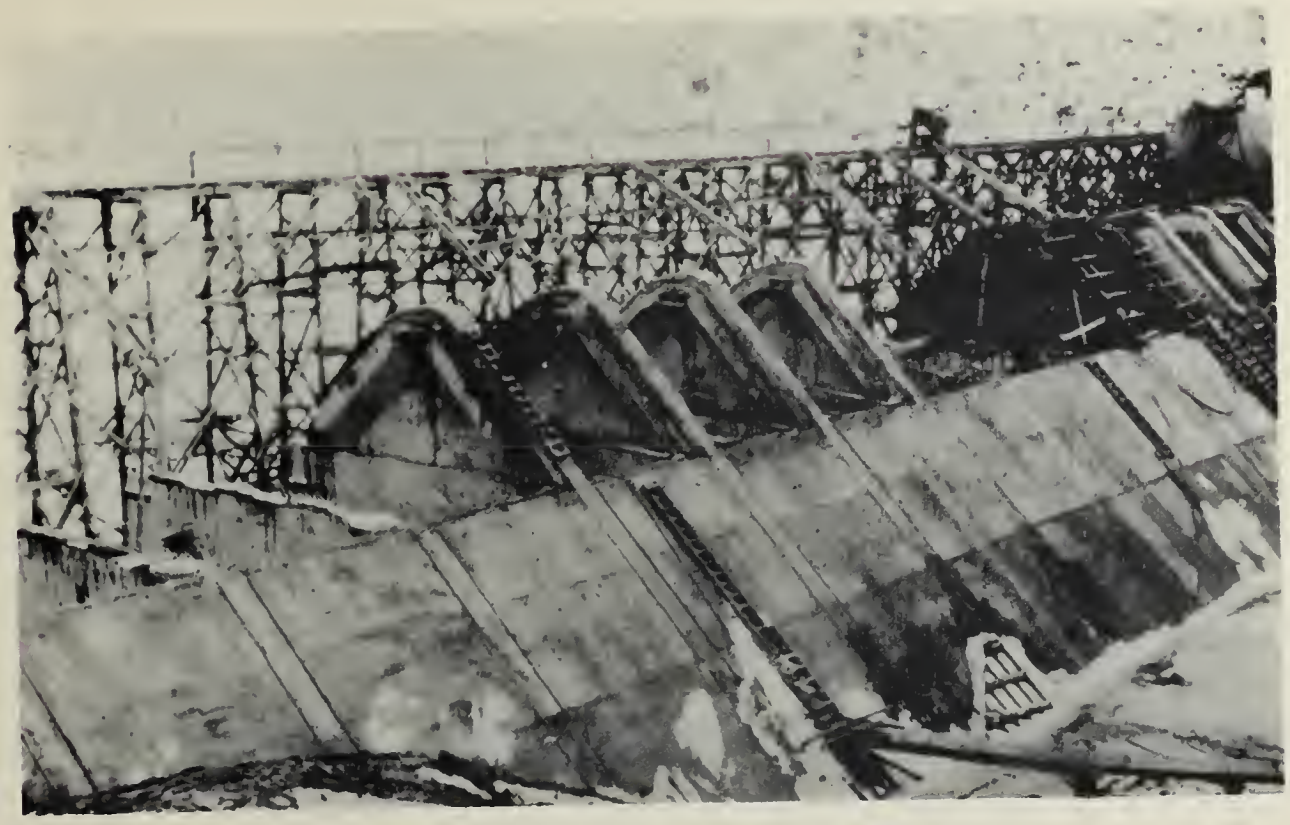
BUTTRESS DAM DESIGN

MAJOR TYPES OF
DECK, TRANSITION SECTION,
BUTTRESS, AND BUTTRESS STIFFENING

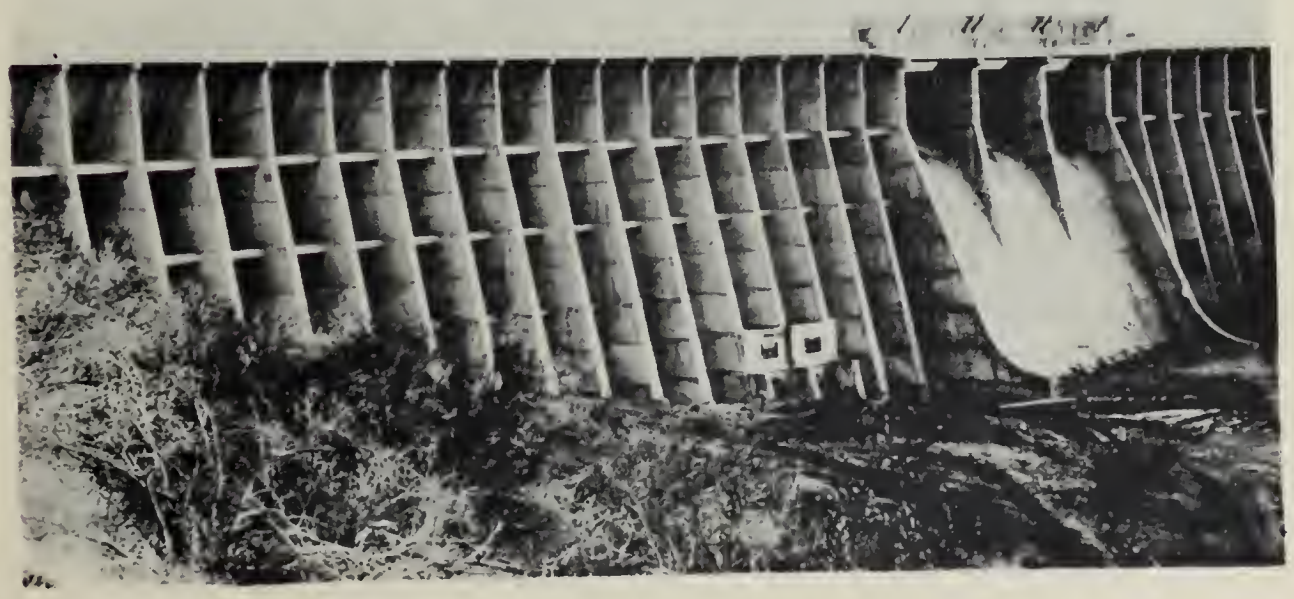
BMJ 6-28-38 REV. 3-20-46 E.R.D

X-D-2430

FIG. 2 par. 5.4.2.

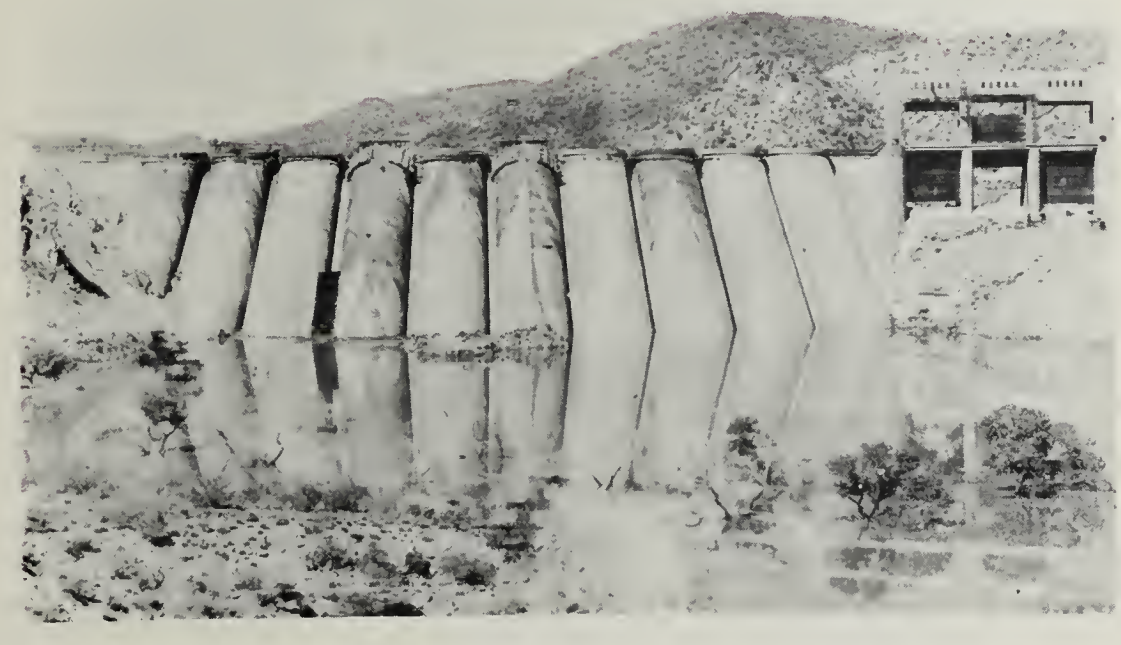


UPSTREAM FACE OF THIEF VALLEY DAM, OREGON
DURING CONSTRUCTION



DOWNSTREAM SIDE OF STONY GORGE DAM, CALIFORNIA
AFTER COMPLETION

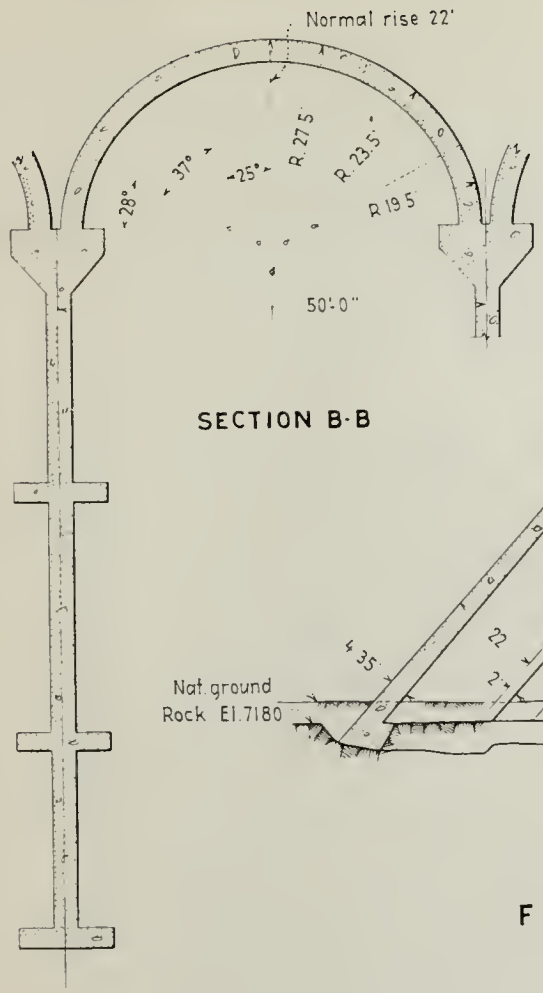
FIG. 3 par. 5.4.2.

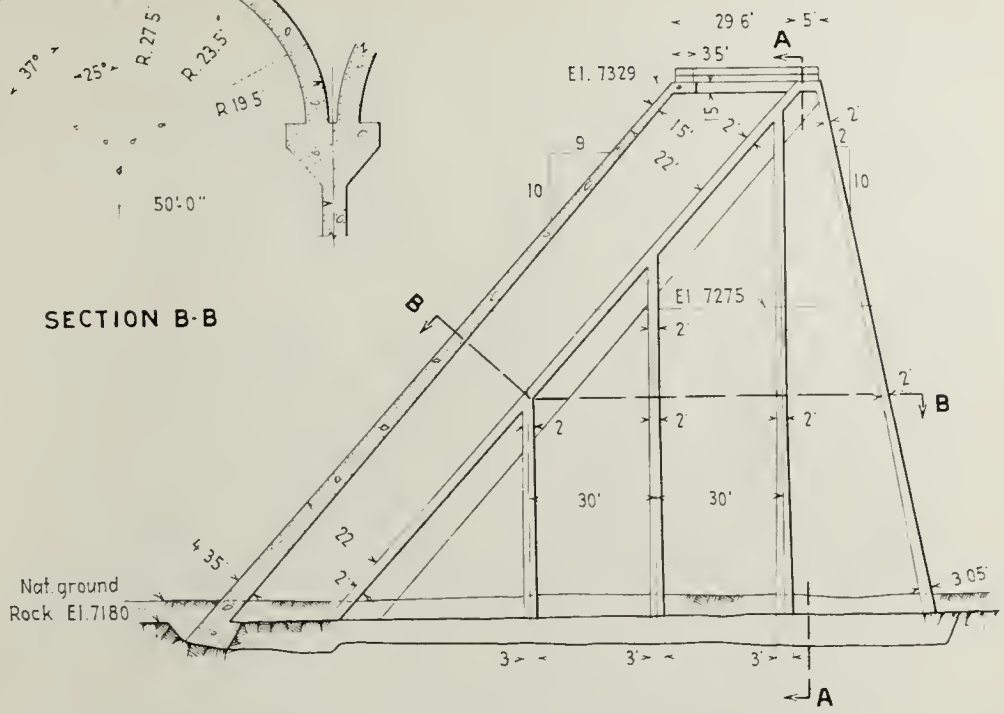


UPSTREAM FACE OF BARTLETT DAM, ARIZONA
NEARING COMPLETION

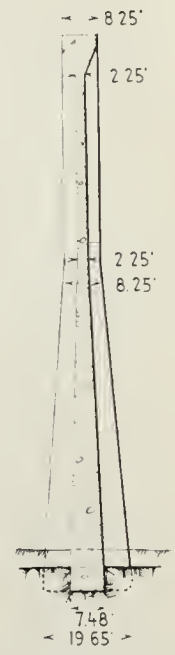
DOWNSTREAM SIDE OF BARTLETT DAM, ARIZONA
AFTER COMPLETION

FIG. 4 par. 5. 4. 2



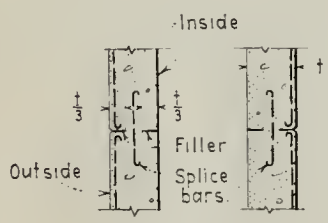


SECTION THRU ℄ OF ARCH

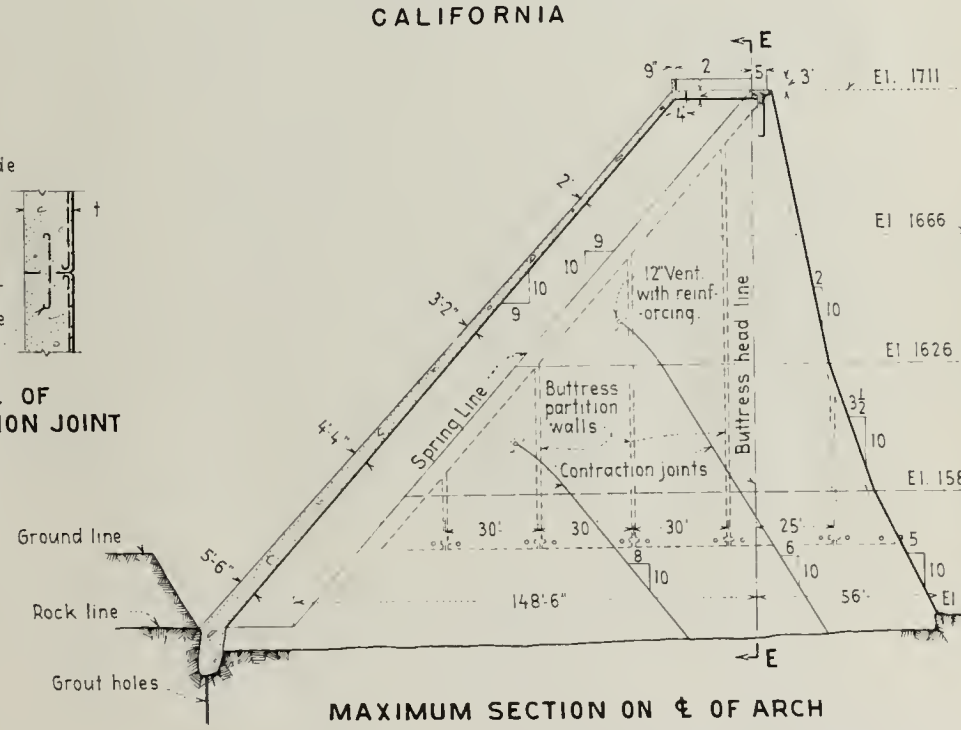


SECTION A-A

FLORENCE LAKE
CALIFORNIA



DETAIL OF CONTRACTION JOINT



MAXIMUM SECTION ON ℄ OF ARCH

SECTION E-E

BIG DALTON
CALIFORNIA

NOTES:-

Details of Florence Lake Dam obtained from Western Construction News (July 25, 1927.)

Details of Big Dalton Dam obtained from Engineering News Record. (December 26, 1929)

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

BUTTRESS DAM DESIGN

TYPICAL BUTTRESSES

DRAWN	B M J	SUBMITTED	
TRACED	L R H	RECOMMENDED	
CHECKED		APPROVED	
		DENVER, COLO. MAY 6, 1936	X-D-1825

(.2D)

dam, in which a dome-shaped deck section spans each of the spaces between adjacent buttresses, is a modification of the multiple-arch type. The unique example of the multiple-dome type is Coolidge Dam in Arizona. This dam is 250 feet high and consists of three domes supported by massive buttresses at 180 feet centers. Some economy is claimed for this type of dam.

DESIGN CONSIDERATIONS

.3 Factors which are considered in selection of type of dam for a given requirement at a particular site are: the site conditions, such as topographic and geologic conditions; the project requirements, such as height of dam, spillway and outlet requirements; basic assumptions, including limiting stresses and factors of safety; and cost. Discussion is included of those features favorable to buttress dams ingeneral and to the suitability of the various types of buttress dams to particular conditions.

SITE CONDITIONS

.4 In a wide valley, where a long dam is required, the buttress dam usually has an advantage over the solid concrete dam by reason of economy in materials and total cost. Where an overflow spillway is required or outlet works extend through the dam, the buttress dam may also be more economical than the earth-fill or rock-fill dam. An overflow spillway on an embankment dam requires special treatment which usually increases the cost. Outlet works through an embankment dam will necessarily be much longer and, therefore, more expensive than similar outlet works through a buttress dam. The geological character of the foundation material underlying the site is a consideration in the selection of any type of dam. As stated before, it may be feasible to construct a buttress dam on a foundation too weak to support a solid concrete dam. Low unit loadings on the foundation may be obtained through the use of spread footings for the buttresses.

STRUCTURAL REQUIREMENTS

.5 In determining whether a buttress dam is the most desirable type to be used at a given site, the following factors must be taken into account:

HEIGHT OF DAM

A. The present maximum height of buttress dams is about 300 feet. However, there is no reason that buttress dams cannot be built to heights more than double this value. Height limitation, therefore, does not preclude the use of buttress dams for even the highest dams.

(.5)

TYPES OF DECK

B. Choice of type of buttress dam, which is in effect the choice of type of deck to be used in a particular location, is usually determined by comparative estimates of cost of the several types. The following general advantages and disadvantages of each type are considered in the choice.

FLAT-SLAB DECK

(1) Flat-slab decks are particularly economical and practical for low dams, where other types may not be suitable. However, this type is not restricted to low dams. The units of this type of dam are independent structurally, hence foundation settlements will have little effect on distribution of foundations stresses. Disadvantages of this type are the complete dependence upon the tension steel of the slab for support of the imposed loads, and the possibility of the face slab loading the edges of the corbel, thus causing stress concentrations in the corbel.

MULTIPLE-ARCH DECK

(2) Generally the multiple-arch deck is most suitable for the higher buttress dams, and buttress spacings may be 50 or 60 feet. Such a dam is a continuous structure in which the stability of each unit may be dependent upon the stability of adjacent units. Despite some objection to the multiple-arch dam for this reason, no failures of this type are known to have occurred due to structural faults in design. With 180 degree arches, which is the most usual design, the lateral thrust is so small that dependence for stability of one unit is not placed upon adjacent units.

MASSIVE-HEAD DECK

(3) For lower dams, the spacing of buttresses may be such that a massive-head design may be more economical than the multiple-arch and may compare favorably with the flat-slab type. Since the head is designed so that weight and water load induce only compressive stresses in the structure, very little or no reinforcement may be required with the massive-head type, which may be a factor favoring its selection. This type of dam is heavier and has greater sectional area on horizontal planes, so that resistance to sliding is greater and the shear safety factor is higher than with other types.

(5B(3))

Since the units are independent structurally, small unequal foundation settlements may be permissible.

C. The two general types of buttresses are the hollow or double-wall, and the solid or single-wall buttress. Materials and form-work are least for single-wall buttresses, but this type requires stiffening for any but rather low dams. Stiffeners may be either structural members which connect adjacent buttresses or they may be bracing walls. The two types are shown in Figure 1. TYPES OF BUTTRESS

.6 As a basis for the design of buttress dams, the following assumptions are made: BASIC ASSUMPTIONS

A. The working stress for concrete most commonly used in the design of buttress dams is 650 pounds per square inch. In massive buttresses, where little or no reinforcement is used, the allowable stresses are reduced to conform with the class of concrete. The actual unit weight of the concrete should be used in the design, but a unit weight of 150 pounds per cubic foot is often used for preliminary design purposes. LIMITING STRESSES

B. Buttress dams should satisfy shear safety factor and sliding factor requirements. Limiting values of stability factors are largely dependent upon foundation conditions and methods of construction. For sliding factors, the usual practice is to limit the ratio of total horizontal forces above a horizontal plane to total vertical forces acting on the plane to 0.65 for normal loading conditions, and 0.75 when including earthquake effects. For shear safety factors, under the same conditions, minimum values would be 6.0 and 5.0, respectively. Of the two criteria, shear safety factor is becoming the more acceptable criterion for judging the safety of a dam against sliding. A full discussion of these criteria is given in Chapter 5.2. FACTORS OF SAFETY

.7 Although local considerations will influence relative costs, there are certain features which may be favorable to the buttress dam regardless of locality. Rock and earth excavation may be less. It is possible to locate outlet works either between buttresses or in the center of the hollow buttresses where such buttresses are used. This permits economical construction and access for inspection. Power houses or other ECONOMIC CONSIDERATIONS

ECONOMIC CONSIDERATIONS (CONT.)

(.7) appurtenant works may be located in the space between buttresses. Remoteness of some sites from established transportation facilities has favored selection of the buttress type of dam because of the smaller quantity of concrete required and the high cost of cement at such sites. Where a valley is wide and a long dam is required, the buttress dam may have an economic advantage over a solid concrete dam. If at the same time suitable separate spillway and outlet possibilities do not exist so that an overflow spillway is required and outlet works must be carried through the dam, the buttress dam may also be more economical than an earth-fill dam.

PRELIMINARY DESIGN

.8 The layout of a buttress dam involves two separate considerations:

(1) Selection of the most suitable type, flat-slab, multiple-arch, or massive-head, influenced largely by such local conditions as topography, geology, and accessibility, and

(2) The economies possible within the type selected by varying buttress spacing, upstream slope, class of concrete, etc.

The latter point is best studied by determining actual quantities and comparative costs for a number of designs involving changes in the variable factors, and selecting the most economical set.

DESIGN LOADS

.9 The loads usually considered in the design of a buttress dam are contributed by water and ice thrust, dead weight, temperature and shrinkage, earthquake, uplift, tailwater, and silt.

WATER AND ICE LOADS

A. The water or live load in design is that load to which the structure or any part may be subjected by the critical water-surface elevation. Additions to this might be wave action, or ice pressure. Stresses should be computed for all possible loads. If the condition of loading is temporary, higher stresses might be allowed.

The heavy thrusts from ice formation should be considered where there is a possibility of this load. The thrust to be expected depends upon the depth of ice to be encountered, temperature conditions, the fluctuation of the water surface, the character and location of shores with respect

(.9A)

to the dam, and the slope of the upstream face of the dam. Usual practice when considering ice thrust is to use a load of 3,000 to 10,000 pounds per lineal foot applied horizontally at the level of the spillway crest.

B. The weight of the deck, transition section, buttresses, footings, and stiffeners is normally all of the dead weight that is used in the preliminary determination of buttress spacing. In addition to the foregoing, the effect of the weight of appurtenant features, such as spillway piers, gates, superstructure, roadways, and walkways, must be considered in the final design and stress analysis. DEAD WEIGHT

The deck weight may be treated either as though the deck were joined to the buttresses with frictionless joints or as though deck and buttresses were constructed monolithically. The two conditions for a multiple-arch dam are illustrated in Figure 5. While the final design will not be changed greatly by whichever assumption is used, choice will be made by judging which assumption more closely approaches the actual conditions.

C. Volume change, particularly contraction due to reduction in temperature and shrinkage due to loss of moisture, will determine the provisions affecting both design and construction that must be made for control of cracking. Cracks are of particular concern in the deck, where percolating water may rust reinforcing steel, deteriorate concrete by leaching the soluble parts, or spall off surfaces by freezing in the pores of the concrete. Temperature effects have been controlled by proper design of reinforcing steel, by proper choice and use of materials in the concrete mix, such as use of low-heat or puzzolan cements and aggregates with favorable thermal properties, by limitation of height of lift and rate of placement of concrete, by artificial cooling, and by the use of contraction joints. Cracks due to shrinkage stresses may also be controlled by the use of reinforcement and by judicious location of contraction joints. Temperature and shrinkage effects may be computed together by adding to the expected change of temperature of the concrete an additional temperature change equivalent to the estimated shrinkage of the concrete. TEMPERATURE AND SHRINKAGE

(.9)

C UPLIFT

D. The effect of uplift pressure will be small on the relatively thin structure of a buttress dam, but it should be investigated. Since the greatest effect is at the upstream face, uplift will shift the position of the resultant of the forces at the base of the dam, and investigation should be made to see that the resultant is not shifted to the extent that tensile stress may exist at the upstream edge of the base.

TAILWATER

E. Forces due to tailwater may affect the stability factors of the dam. Uplift pressure caused by tailwater, although ordinarily small in magnitude, may be of importance if high tailwater is a possibility, especially where the buttresses rest upon spread footings.

EARTHQUAKE

F. The effect of earthquake shock upon the stresses and stability factors of buttress dams may be investigated in the same manner as described for gravity dams in Chapter 5.2. The earthquake shock is generally assumed to produce an acceleration of the mass of the dam and the water of one-tenth gravity, acting for a period of one second.

SILT

G. Silting of the reservoir may in time place additional load on the dam. There is disagreement as to whether silt pressure is that of a consolidated mass, or follows the laws of fluid pressure. If the silt is assumed to be consolidated, its principal effect will be to increase the concrete stresses. If the silt acts as a fluid, conditions of stability may also be affected. For design purposes, the worst condition should be assumed for each criterion of failure.

UPSTREAM SLOPE AND BUTTRESS SPACING

.10 About one-half of the existing buttress dams have upstream face slopes of 45 to 48 degrees from the horizontal, and practically none less than 40 degrees. In existing flat-slab dams, buttress spacing is 18 feet for heights up to 150 feet, and one dam 240 feet high has a spacing of 22 feet. In existing multiple-arch dams, no definite relationship exists between buttress spacing and height, as spacing varies widely from 24 to 84 feet. However, the general trend is to employ spacings increasing from 40 to 60 feet for dam heights increasing from 100 to 285 feet.

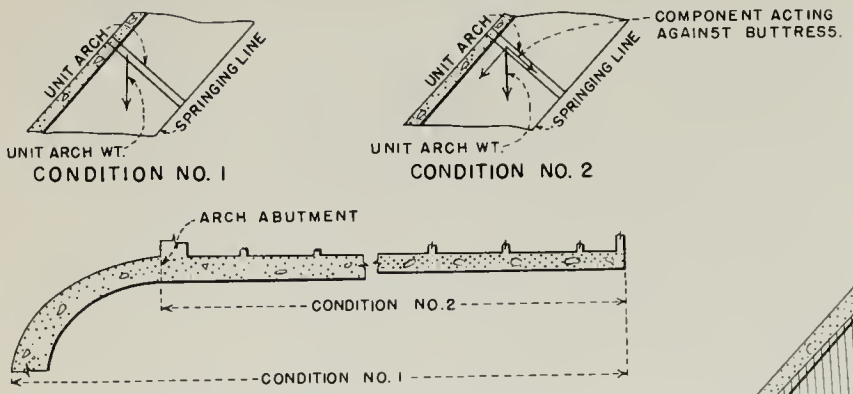
STRESSES ON HORIZONTAL SECTIONS

CONDITION NO. 1

ELEV.	VERTICAL STRESS		CONCRETE STRESS PARALLEL TO FACE		AVERAGE SHEAR	STABILITY FACTORS	
	U	D	U	D		S.F.	Q
1750	81	122	11	138	48	0.583	16.3
1650	174	311	14	351	147	0.678	5.7
1540	239	451	32	509	211	0.667	4.3

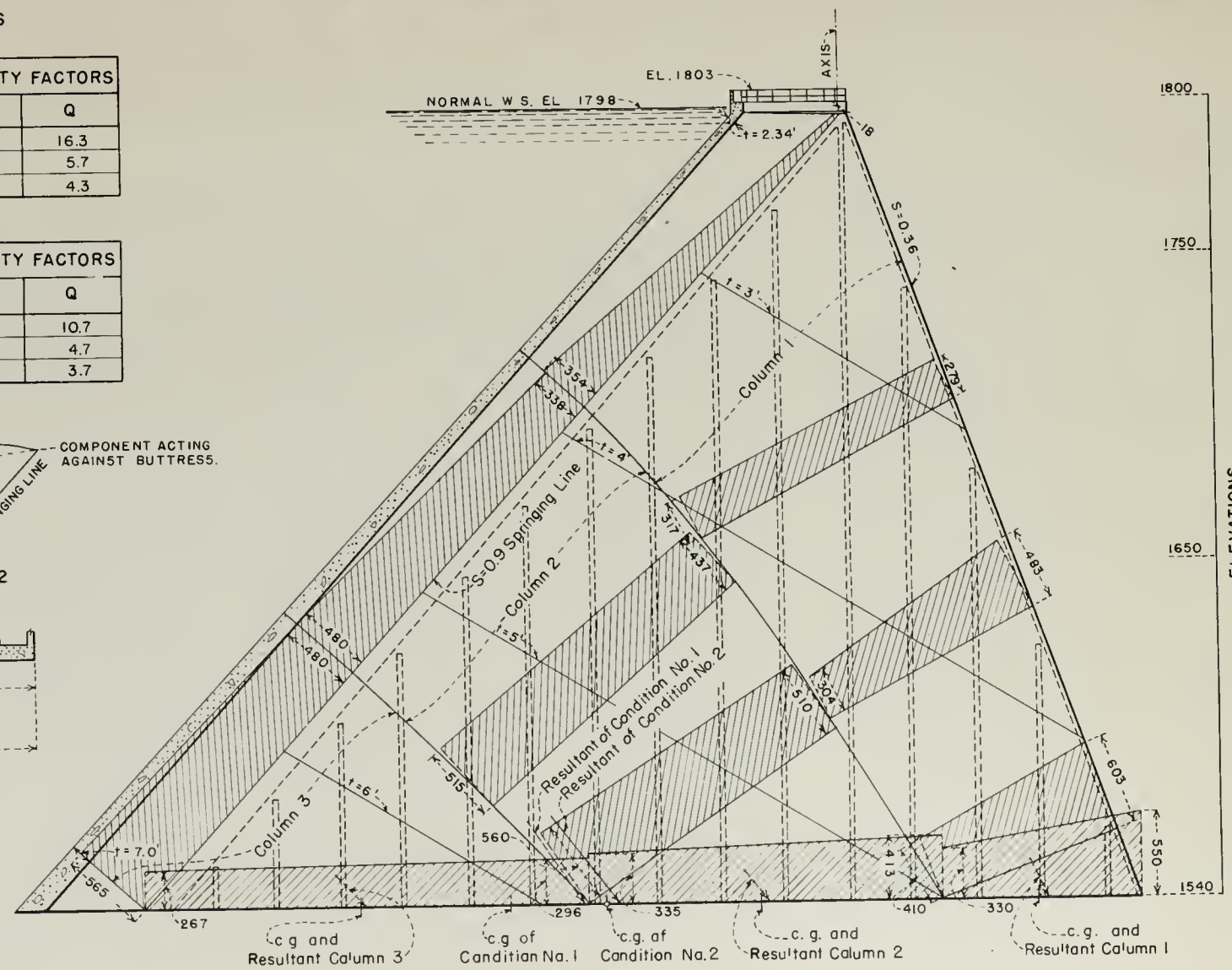
CONDITION NO. 2

ELEV.	VERTICAL STRESS		CONCRETE STRESS PARALLEL TO FACE		AVERAGE SHEAR	STABILITY FACTORS	
	U	D	U	D		S.F.	Q
1750	89	105	25	118	71	0.737	10.7
1650	180	300	25	339	181	0.766	4.7
1540	244	450	42	508	248	0.730	3.7



CONDITION NO. 1 CONDITION NO. 2

STRESSED AREAS FOR ANALYSIS BY HORIZONTAL SECTIONS



NOTES

Condition No. 1 assumes that arch and buttress are monolithic.
Condition No. 2 assumes that the arch and buttress are separated by a frictionless joint, and that only the component of arch weight normal to the springing line acts as a load on the buttress.
Unit weight of concrete = 150 lb. per cu. ft.
U = Stress at upstream face of buttress.
D = Stress at downstream face of buttress.
All stresses are in lb. per sq. in.
All normal stresses are compressive except those preceded by a negative (−) sign which are tensile.
All shear stresses are positive and are caused by forces acting thus ⇌.
All resultants shown are for condition of reservoir full.

$$S.F. = \text{Sliding Factor} = \frac{\text{Horizontal Force}}{\text{Vertical Force}}$$

$$Q = \text{Shear-friction safety factor} = \frac{(\text{Total Vertical Force})\, f + As}{\text{Total Horizontal Force}}$$

f = Coefficient of internal friction = 0.65
A = Area of section.
S = Unit shear resistance = 700 lb. per sq. in.
For additional dimensions see Drawing No. 25-D-1015.

NORMAL STRESSES BY COLUMN ANALYSIS

(Based on the assumption of frictionless joints between columns and that the arch weight is applied as in Condition No. 2.)

10 0 10 20 30 40 50
SCALE OF FEET

400 0 400 800
SCALE OF STRESS LB. PER SQ. IN.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT RIVER PROJECT – ARIZONA

BARTLETT DAM

BUTTRESS STRESSES – NORMAL W.S. EL. 1798
DESIGN STUDY DRAWING

DRAWN G.I.B. A.A.F. SUBMITTED
TRACED T.J.K. N.H. RECOMMENDED
CHECKED B.M.J. APPROVED
DENVER, COLO. JULY 10, 1936. 25-D-1302
REV 1-19-44

FIG. 5 par. 5.4.9

(.10) Bureau studies show that for multiple-arch dams, for the usual range of heights, buttress spacings of 50 to 60 feet and upstream slopes of approximately 45 degrees are most economical, and that corresponding values for flat-slab dams are 18 to 24 feet for buttress spacings and 47 degrees for upstream slope. When local conditions permit, median values in these ranges may be chosen as the basis of preliminary design.

TRANSITION SECTION

.11 A transition section is usually required to transfer the water load and the deck weight to the buttresses. This is illustrated in Figure 1. For single-wall buttresses this section is usually a corbel, but for double-wall buttresses the transition section may consist of a slab over the hollow buttress with special design of reinforcement in the slab but with very little change in the buttress detail.

CORBELS--FLAT-SLAB DECKS

A. For the flat-slab deck, the design of the corbel is based on conventional methods of analysis in which the corbel width is determined by the bearing area required to support the deck and the depth is determined by shear requirements or sometimes by moment requirements. The corbels should have the bearing surfaces so shaped that the deck reaction will not load the edge and cause stress concentrations.

CORBELS AND SLABS--MULTIPLE-ARCH DAMS

B. In multiple-arch dams, both single-wall and double-wall buttresses are used; typical sections of each are shown in Figures 1 and 4. In design of the slab over the double-wall buttress, the thickness of the slab, as well as the reinforcement, is determined by the requirements for moment and shear. In multiple-arch dams with single-wall buttresses, corbels are used which may be similar in appearance to the corbels of flat-slab dams but are stressed differently on account of the rigid connection of arch and buttress. The corbel may have areas of high stress concentration due to re-entrant corners. The problem of determining corbel stresses for this case becomes highly indeterminate, and is best solved by photoelastic or other complex mathematical means.

DESIGN OF BUTTRESSES

.12 Buttresses, like massive dams, are highly indeterminate structures, and design is made on the basis of simplifying assumptions and time-tested criteria.

(.12)

LOADS

A. For dimensioning the buttress, the design loads on the upstream edge are the direct water load and the normal component of the weight of the deck and transition sections. Other loads, due to ice pressure, wave action, earthquake shock, and weight of appurtenant structures, are used to check this design, using increased allowable stresses when the temporary nature of the loading permits.

COLUMN ASSUMPTION

B. Each buttress is designed on the assumption that it is made up of a number of unit columns of uniform strength, arched along catenary boundaries. Each column is assumed to transfer the load due to water pressure and concrete weight from the top of the column to the foundation, independent of the column adjacent to it.

DESIGN PROCEDURE

C. The method of procedure for the design of buttresses is given in Figure 6. This method begins with the computation of ϕ_o, the angle of the resultant of external load with the horizontal, and t_o, the initial thickness of the buttress to resist this load. Computed values of ϕ_o and t_o may be checked by plotting against elevation, as each plot should result in a smooth curve. Catenary curves are drawn from convenient points at the upstream face of the buttress, thus defining the axis of the unit column. As the load in the unit column increases approaching the foundation due to the weight of the concrete in this column, the thickness of the unit column is increased in accordance with the method of computation given in Figure 6.

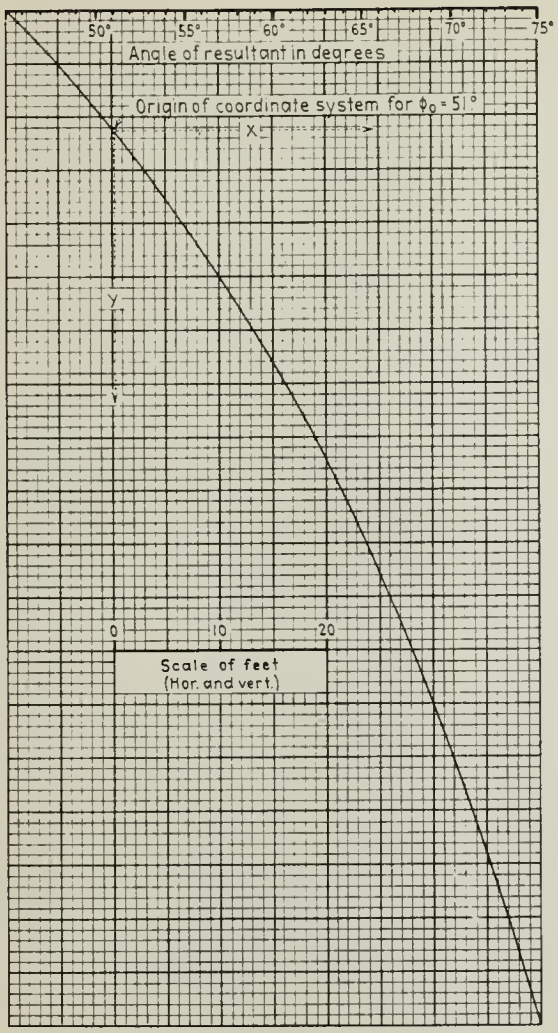
ANTI-BUCKLING RATIO

D. Both the hollow type and the massive single-wall type of buttress must be of such thickness as to satisfy the anti-buckling requirement that the thickness be from one-twelfth to one-fifteenth the unsupported length.

STIFFENERS

E. In the case of thin single-wall buttresses, a choice of solutions is offered to meet the anti-buckling requirement. With the thickness fixed, the unsupported length is reduced by means of struts, diaphragms, or counterforts so that the thickness-to-length ratio is brought within allowable limits. When struts or diaphragms are used, each buttress is stiffened by adjacent buttresses and, ultimately, the foundations, and the allowable unsupported length is 12 to 15 times the buttress thickness.

FIG. 6 par. 5.4.12



DERIVATION

"The Buttressed Dam of Uniform Strength
(By Herman Schorer · Am. Soc. C.E. Trans. Vol 96 (1932) p. 666)

NOTATION

$C = f_c \frac{144}{w_c} = 96.0$ feet, in which

f_c = unit compressive stress in concrete = 100 lbs./sq. in

w_c = unit weight of concrete = 150 lbs./cu. ft

P_0 = resultant force on top of unit catenary column.

P_x = resultant force along unit catenary column.

P = component of P_0 normal to top of unit catenary column

A = area of column cross section.

ϕ_0 = angle of external resultant P_0 with horizontal, degrees

ϕ_x = angle of internal resultant P_x with horizontal, degrees

e = base of Naperian logarithms

t_0 = thickness of unit catenary column at top

t_x = thickness of unit catenary column at any point along column.

Thicknesses are dimensions normal to plane of drawing

x = horizontal coordinate of catenary

y = vertical coordinate of catenary

Y = vertical distance on catenary to points of increased thickness.

Axis of column is line of centers of gravity of column cross-section.

Unit catenary column boundaries ——·····——·····——

Catenary lines. —— —— —— —— —— ——

Uniform thickness lines ----------

All linear dimensions are in feet and all forces are in pounds.

ADAPTATION

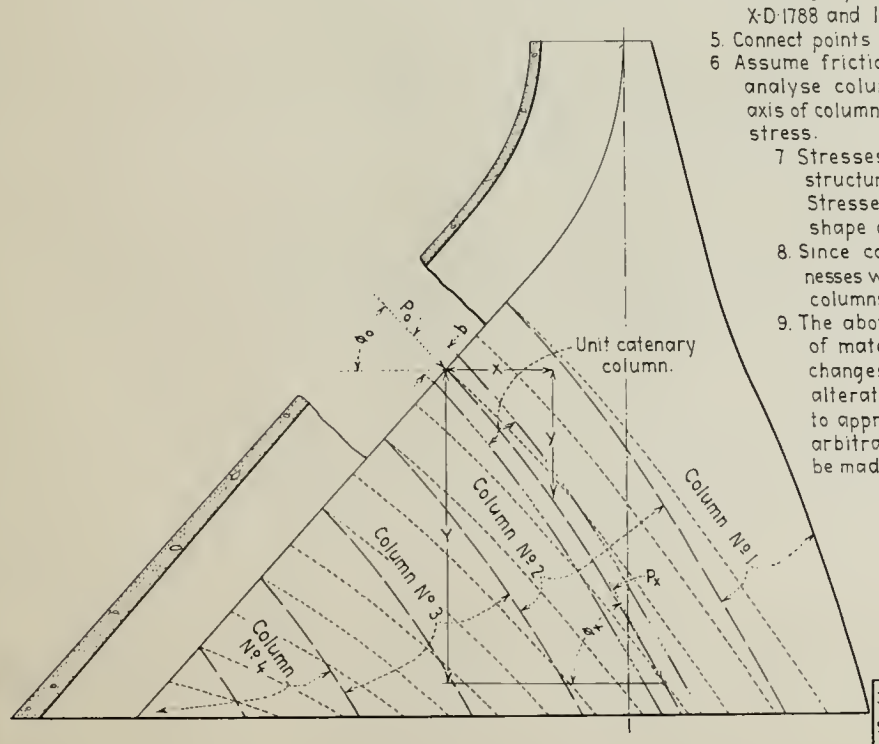
Catenary shown is for values of f_c = 100 lbs/sq. in. and w_c = 150 lbs./cu. ft. For values of x and y corresponding to other design values of f_c and w_c apply a factor based on the ratio of a new value of C to the value of C given on this drawing.

CALCULATION

$$X = C \frac{\pi}{180} (\phi_x - \phi_0) \qquad y = \frac{C}{\log e} (\log \sec \phi_x - \log \sec \phi_0) \qquad Y = \frac{C}{\log e} (\log t_x - \log t_0)$$

CONSTRUCTION

1. Assume f_c, w_c, slope of upstream buttress face, and design features at top of buttress.
2. Combine external loads on buttress face and determine required thickness t_0 along buttress face by $P/A = f_c$
3. At representative points having convenient values of t_0, determine ϕ_0 and reproduce the section of the catenary needed, using the intersection of the catenary and the ordinate line of ϕ_0 as an origin of a coordinate system.
4. Using formula $Y = \frac{C}{\log e} (\log t_x - \log t_0)$, assume values of t_x which are greater than t_0 by definite increments of thickness. Obtain values of Y from Drawing X-D-1788 and locate positions of values of t_x on catenary
5. Connect points of equal thickness by smooth curves.
6. Assume frictionless joints along catenary lines similar to Fig 2, and analyse columns by checking line of resultant. At any section normal to axis of column, the stress given by $P_x/A \pm Mc/I$ should not exceed the design stress.
   7. Stresses in column No. 1 will deviate from design stress because of structural features in upper parts of buttress and buttress deck. Stresses may be adjusted by changing thickness or downstream shape of column wall.
   8. Since column No. 2 is dimensioned closely in accord with theory, thicknesses will give close to allowable stresses. The same is true for columns No. 3, 4 etc
   9. The above gives a structure which is theoretically safe and economical of materials. Simplicity and economy in construction may dictate changes, such as the lines of equal thickness to be straight lines. Such alterations may increase weight of column enough to cause resultant to approach the vertical near the base, and it may be necessary to arbitrarily change column shape from the theoretical. Adjustment must be made by trial, and design checked by column analysis as before.



DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

BUTTRESS DAM DESIGN

METHOD OF PROCEDURE

FOR DESIGN OF BUTTRESS

DRAWN	B.M.J.	SUBMITTED	
TRACED	L.R.M.	RECOMMENDED	
CHECKED	T.B.	APPROVED	

REV. 11-15-44

DENVER, COLO. MAY 6, 1936

X-D-1784

(.12E)

When counterforts are used, the interval between counterforts is made 12 to 15 times the buttress thickness, and the overall width of the counterfort, which is the thickness of the buttress plus the projection of the counterforts on both sides of the buttress, is made one-seventh the height of the counterfort. Figure 4 shows the use of counterforts in a single-wall buttress, and diaphragms or partition walls in a double-wall buttress.

F. Simplicity of detail and economy of construction may be increased by straightening the lines of equal thickness, and the downstream profile of the buttress. After these and other possible changes are made, column alinement must be made by trial, and the design checked by column analysis as before.

CHANGES FOR EASE IN CONSTRUCTION

.13 The design of the deck of a buttress dam naturally depends on the type of deck under consideration.

DESIGN OF DECK

A. The flat-slab type of deck may be designed for moment and checked for shear by the usual theoretical methods for reinforced-concrete beams. For preliminary purposes, the slab thickness may be obtained from the following formula, which is based on a unit flexural stress of 750 pounds per square inch for concrete and 18,000 pounds per square inch for steel.

FLAT-SLAB DECK

$$d = \frac{1}{10}\sqrt{M} + C$$

where d = total depth in inches
M = total moment in foot-pounds
C = steel coverage in inches

Dimensions thus determined for moment may also be adequate for shear, but if the shear stresses are high the addition of proper reinforcement may be required.

B. The barrel of the multiple-arch type of deck is designed in two parts--the complete arches, and the partial arches. Figure 1 shows the distinction between the two parts.

MULTIPLE-ARCH BARREL

(1) A vigorous analysis of the arch barrel would involve the use of a trial-load stress analysis assuming the barrel to be composed of mutually perpendicular arch and beam elements. However, the complete arches are usually analyzed

DEFLECTION ADJUSTMENTS

(.13B(1))

DEFLECTION ADJUSTMENTS (CONT.)

assuming independent arch elements normal to the springing line of the arch barrel. With this assumption, and for the condition of loading where the variable water load decreases to zero at the crown, the deflections of adjacent arches will differ more than for other load conditions. Since the arches are not free and independent, adjustment and continuity of deflections will be brought about by shear between the arch elements, and by beam action.

LOWER PARTIAL ARCHES

(2) The partial arches at the base of the arch barrel present a difficult problem in stress analysis because the arches usually span between buttresses whose footings are at different elevations, and the arches are therefore nonsymmetrical. Some treatments which have been used in design are: regular construction, as of the normal arches, carried to the bottom; increased reinforcing steel placed in the partial arch; fillets placed on the intrados of the partial arch; and partial arch replaced entirely by gravity section.

UPPER PARTIAL ARCHES

(3) The partial arches at the top of the arch barrel present the most difficult problem in stress analysis of the entire structure. This portion is highly indeterminate, and the validity of any analysis depends to a large extent on the ingenuity of the designer. Treatments which have been used in design of the top partial arches are: regular construction carried to the top; addition of a stiffening rib in the form of an elliptical arch, usually horizontal, along the top; an additional normal stiffening rib near the last complete arch; or varying the slope of the abutment of the arch barrel so that the normal arch elements approach the horizontal at the top of the dam.

MASSIVE-HEAD DECK

C. The main criterion for the design of a massive-head deck is to so shape the heads that the water load can be carried to the buttress in compression. Distribution of stresses may be studied by photoelastic methods, or judged by the suggested criterion that the resultant of the water load fall upstream from the junction of the head and the buttress wall.

.14 A buttress dam may have any or all of the following appurtenant structures: spillway; roadway; walkway; controls for outlet works; spillway gates, piers, and controls; power control houses; and other features of less importance. No general procedure can be outlined for the design of such features, as the requirements vary widely in all situations. However, some sort of preliminary design of such elements must be made to provide an approximate value for the weight of these structures in order to make a complete stress analysis of the buttresses. APPURTENANT STRUCTURES

A. The spillway may be a structure independent of and at some distance from the dam. Design and treatment of such separate spillways are given in Chapter 5.6. In some cases, however, the topographic or geologic conditions make the independent arrangement impossible, and it is then necessary to design a spillway overtopping the dam. SPILLWAY

Buttresses in the spillway section are designed to carry the additional weight of spillway gates, piers, and slab. The downstream edges of those buttresses and the downstream deck slab between them are curved to the shape of the lower nappe of the maximum overflow of water, in the case of an uncontrolled crest. When the flow is controlled by sliding gates or radial gates, the shape of the crest is usually determined to conform to the trajectory of the jet formed by a gate opening of one foot with the water surface at maximum reservoir level. Some form of energy dissipator is usually required with an overflow spillway. The buttresses at the ends of the spillway must support training walls to confine the overflow water. More detailed discussion of the design of overflow spillways may be found in Chapter 5.2.

B. The control of flow of the water from the reservoir for use in regulation of the stream, in irrigation, or in the generation of power is a problem common to all dams. In a buttress dam, the outlet works and controls may be located in the spaces between buttresses, with treatment similar to that described for gravity dams in Chapter 5.2. The design of separate outlet works, part of which may also be applicable to buttress dams, is described in Chapter 5.6. OUTLET WORKS

STRESS ANALYSIS OF BUTTRESSES

.15 After all loads on the buttresses due to the appurtenances have been computed, it is necessary to apply such loads to the buttresses and make a stress analysis of the buttresses under these new additional loads. The procedure in such analysis is the same as that in preliminary design. The buttresses are divided into theoretical catenary columns, and the stresses computed on the sections of these columns. Figure 5 shows the results of such a study. Adjustments to the shape and thickness of the buttresses are usually necessary due to the increased load, to bring the stresses within allowable values. The design is also checked by analysis of the stresses on horizontal sections of the buttresses, assuming a straight line variation of stresses between upstream and downstream edges. If such analysis indicates tension at the upstream edge, further adjustment is made to eliminate tension.

COMPARISON OF METHODS

A. A comparison between the stresses obtained by an analysis of horizontal sections and an analysis assuming columns is shown in Figure 5. Though stresses obtained by these methods are in close agreement, the analysis by columns is desirable since it gives the directions as well as the magnitudes of the principal stresses. Knowledge of those directions will assist in the design of reinforcement and in the location of construction slots and joints for control of shrinkage.

PRACTICAL CONSIDERATIONS

B. There remain to be considered some practical requirements and considerations such as ease and simplicity of forming, placing of reinforcing steel, and location of construction and contraction joints. After provision is made for such practical requirements a final analysis is made to find if such changes affect the stresses in an undesirable manner or cause critical stresses at any point. Adjustments are made to relieve any such effects.

STEEL REINFORCEMENT

.16 The treatment of steel reinforcement in buttress dams differs considerably in the deck, buttress, and footings.

DECK

A. With the exception of the massive-head type, the decks of buttress dams are reinforced primarily to resist tensile stresses induced by structural action, with some additions for temperature stresses. Massive-head decks, being designed for overall compression, need no tensile reinforcement, and their massive dimensions reduce the temperature effect to the extent that very little or no reinforcement is

(.16A)

required. In flat-slab and multiple-arch decks, reinforcing steel is designed in accordance with flexural theory and tied together with temperature steel in a normal direction. Where tensile reinforcement is provided at both faces of the deck, temperature steel is also provided at both faces, the total amount of temperature steel at the thinnest section being about 0.002 of the cross-sectional area of the concrete at that section, with the same amount of temperature steel carried downward into the thicker portions of the deck. In multiple-arch decks, the temperature steel is increased in the region of the arch close to the buttress as added precaution against cracking at this location. DECK (CONT.)

B. In transition sections, reinforcing steel is provided to resist the tensile stresses produced by slab reactions, and dowels extending into the buttresses resist the separation of transition section and buttress. TRANSITION SECTIONS

C. Buttresses seldom require reinforcing steel for structural reasons, even when analyzed for transitory conditions during construction such as wind pressure on a single unbraced buttress. Reinforcing steel is usually placed in buttresses to prevent the formation of cracks due to shrinkage and temperature change. Such steel is placed in vertical mats adjacent to the exposed faces. A common practice is to place the main portion of this steel parallel and adjacent to the deck, carrying it back into the buttress to an arbitrary extent. Other shrinkage and temperature steel is sometimes placed horizontally near the foundation. Vertical spacer bars help keep the mat in alinement during concrete placing, and if several mats are used, they may be tied in position by hooked horizontal bars. No exact analysis of the steel requirement can be made, the quantity being fixed according to judgment and experience. BUTTRESSES

D. Footings, whether individual buttress footings or mat foundations, are reinforced according to the usual practice. Horizontal steel is placed normal to the buttress to give cantilever action, and parallel to the buttress to strengthen the footing against unequal settlement. FOOTINGS

.17 In general, the purpose, procedures, and factors considered in the design and preparation of detailed drawings for specifications which govern the SPECIFICATION DESIGN

(.17)

SPECIFICATION DESIGN (CONT.)

construction of buttress dams are similar to those for gravity dams discussed in Chapter 5.2. Due to this similarity, the following paragraphs discuss only those features included in the above reference which must be modified or completely changed in order to satisfy the characteristics of buttress dams. A complete understanding of the various procedures and considerations necessary for the preparation of the specification design of a buttress dam, therefore, will require a rereading of the above reference in conjunction with the following modifications.

GENERAL DRAWING AND MAXIMUM SECTIONS

.18 Although the procedures in preparation of the general drawing and the drawing of maximum sections and the features shown thereon are similar to those described in Chapter 5.2 for gravity dams, Figures 7, 8, and 9 have been included in this Chapter to illustrate the general arrangement and principal features of such drawings for buttress dam designs.

DIVERSION AND CARE OF THE RIVER

.19 The general discussion of river flow diversion during the construction period, as discussed in Chapter 5.2, applies equally to buttress dams. However, the physical characteristics of buttress dams, which allow a relatively rapid rate of construction, may favor a method of diversion between buttresses at one side of the channel while the section of dam containing the outlet works is being constructed at the other side. Such a method requires a study of the design in order to make sure that the buttresses are capable of withstanding the unbalanced lateral forces due to the depth of the water flowing in the diversion channel or, in the case of multiple arch dams, the unbalanced thrust from the adjacent completed arches.

FOUNDATION TREATMENT

.20 Foundation conditions which are suitable, or can be made suitable, for the construction of buttress dams cover a much wider range than those suitable for gravity dams. Complete adherence to the general principles of foundation treatment, as discussed in Chapter 5.2, may, therefore, be impracticable when the foundation material changes from relatively impervious rock formations to relatively pervious earth formations. In all cases, the width of buttress footings must be sufficient to reduce the foundation stresses to satisfactory limits compatible with the strength of the foundation material, and the rate of seepage must be reduced at least to such an extent as to prohibit the occurrence of piping velocities. In order to satisfy these limitations in

FIG. 7 par. 5.4.18

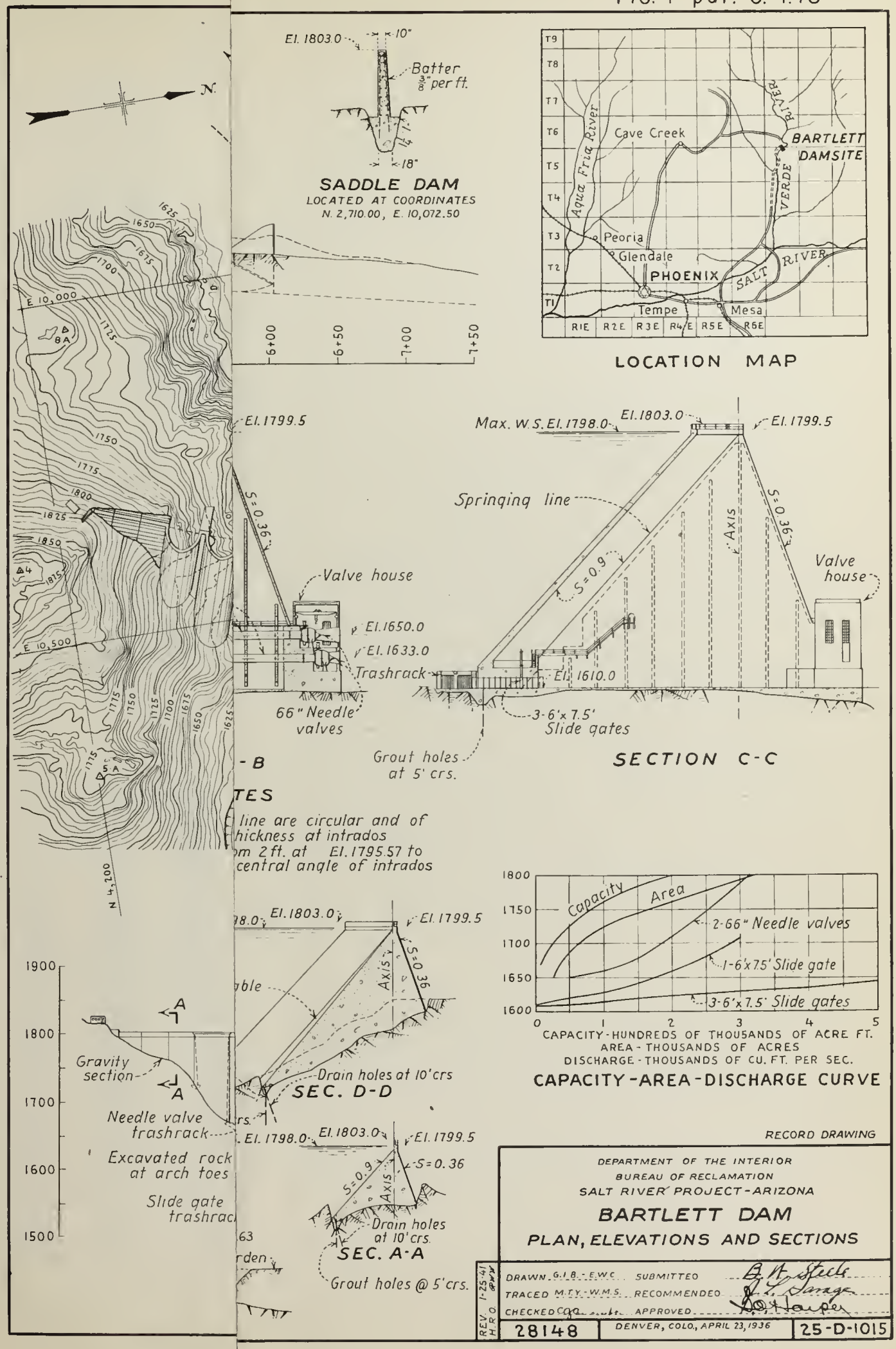
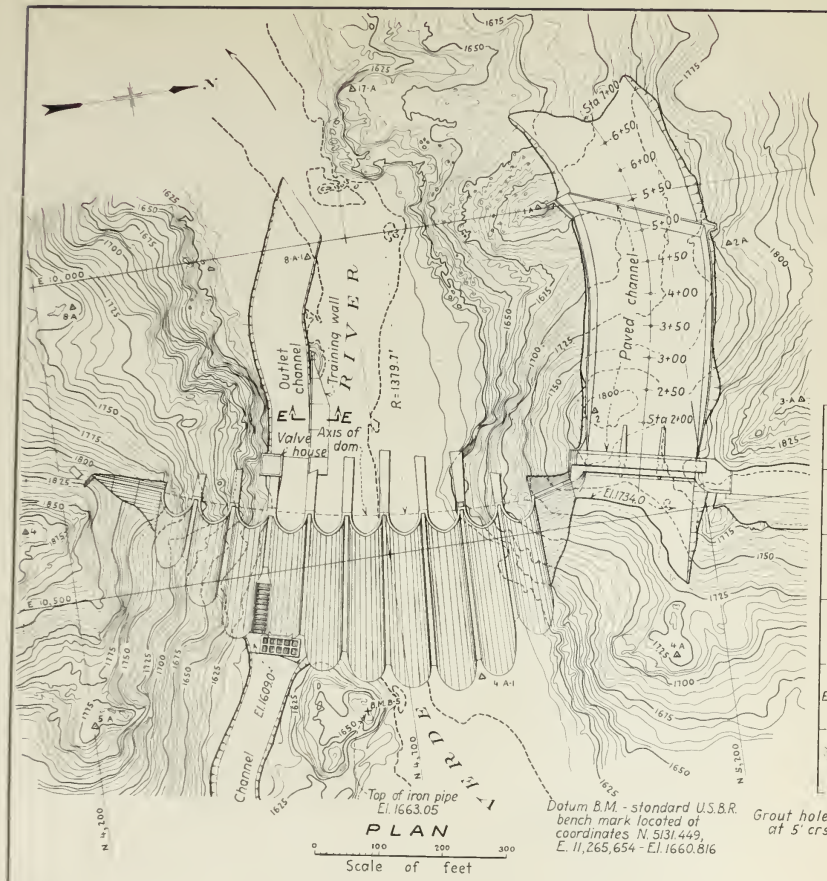
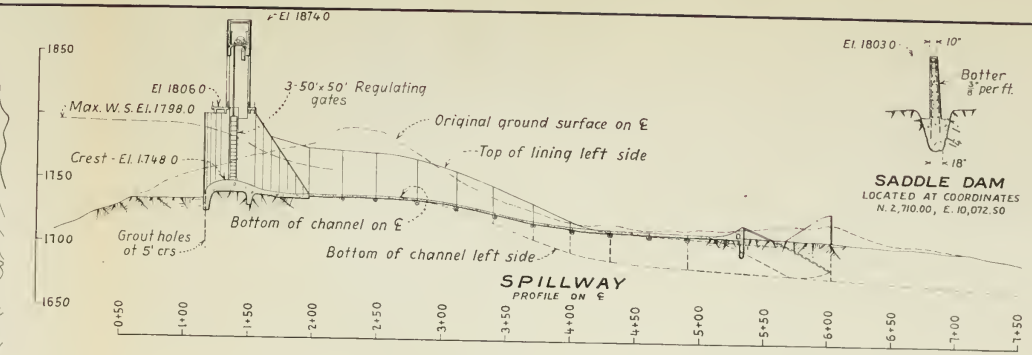


FIG. 7 par. 5.4.18



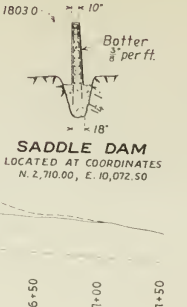
PLAN

Scale of feet



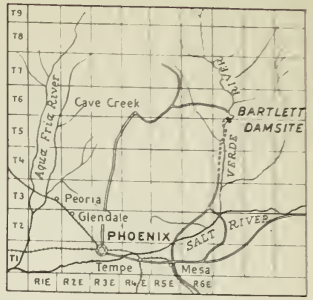
SPILLWAY

PROFILE ON ℄

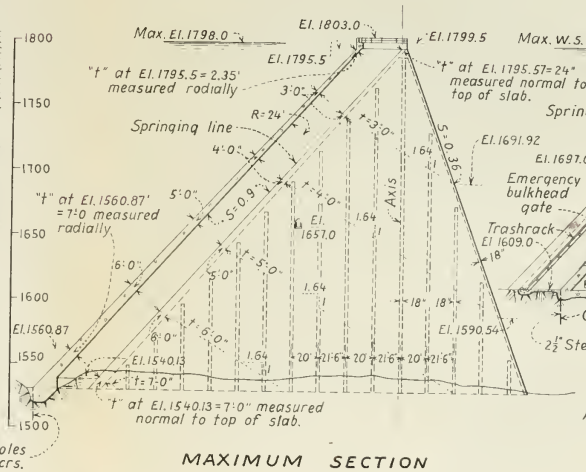


SADDLE DAM

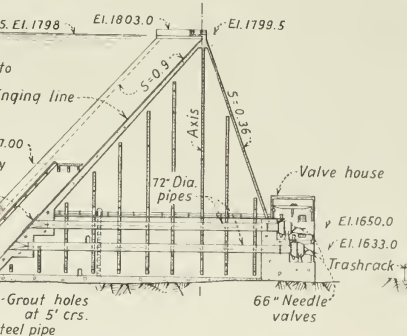
LOCATED AT COORDINATES N. 2,710.00, E. 10,072.50



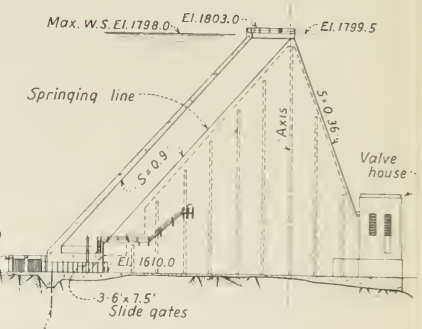
LOCATION MAP



MAXIMUM SECTION



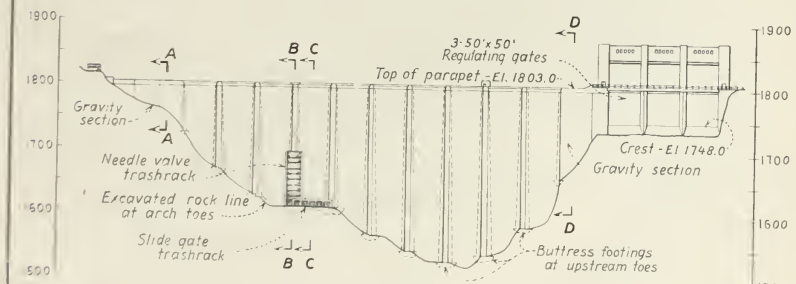
SECTION B-B



SECTION C-C

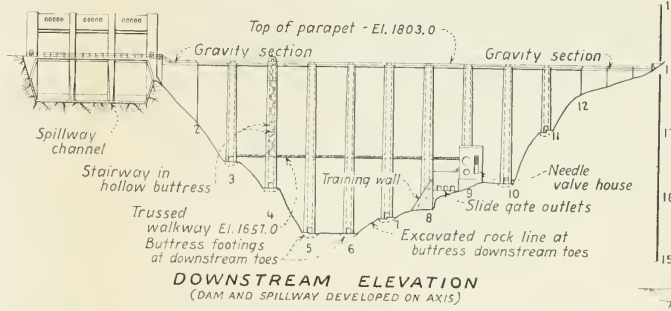
NOTES

Arches normal to springing line are circular and of uniform thickness. Arch thickness at intrados springing line varies from 2 ft. at El. 1795.57 to 1 ft. at El. 1540.13. Total central angle of intrados of normal arch is 180°.



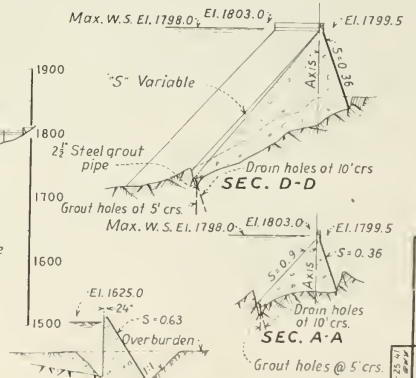
UPSTREAM ELEVATION

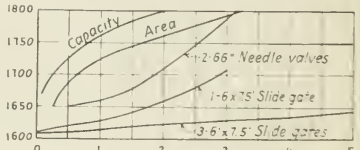
(DAM AND SPILLWAY DEVELOPED ON AXIS)



DOWNSTREAM ELEVATION

(DAM AND SPILLWAY DEVELOPED ON AXIS)





CAPACITY - HUNDREDS OF THOUSANDS OF ACRE FT.
AREA - THOUSANDS OF ACRES
DISCHARGE - THOUSANDS OF CU. FT. PER SEC.

CAPACITY-AREA-DISCHARGE CURVE

RECORD DRAWING

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT RIVER PROJECT - ARIZONA

BARTLETT DAM

PLAN, ELEVATIONS AND SECTIONS

DRAWN G. B. - E.W.C. SUBMITTED
TRACED M.E.K. - W.M.S. RECOMMENDED
CHECKED - APPROVED

28148 | DENVER, COLO. APRIL 25, 1938 | 25-D-1015

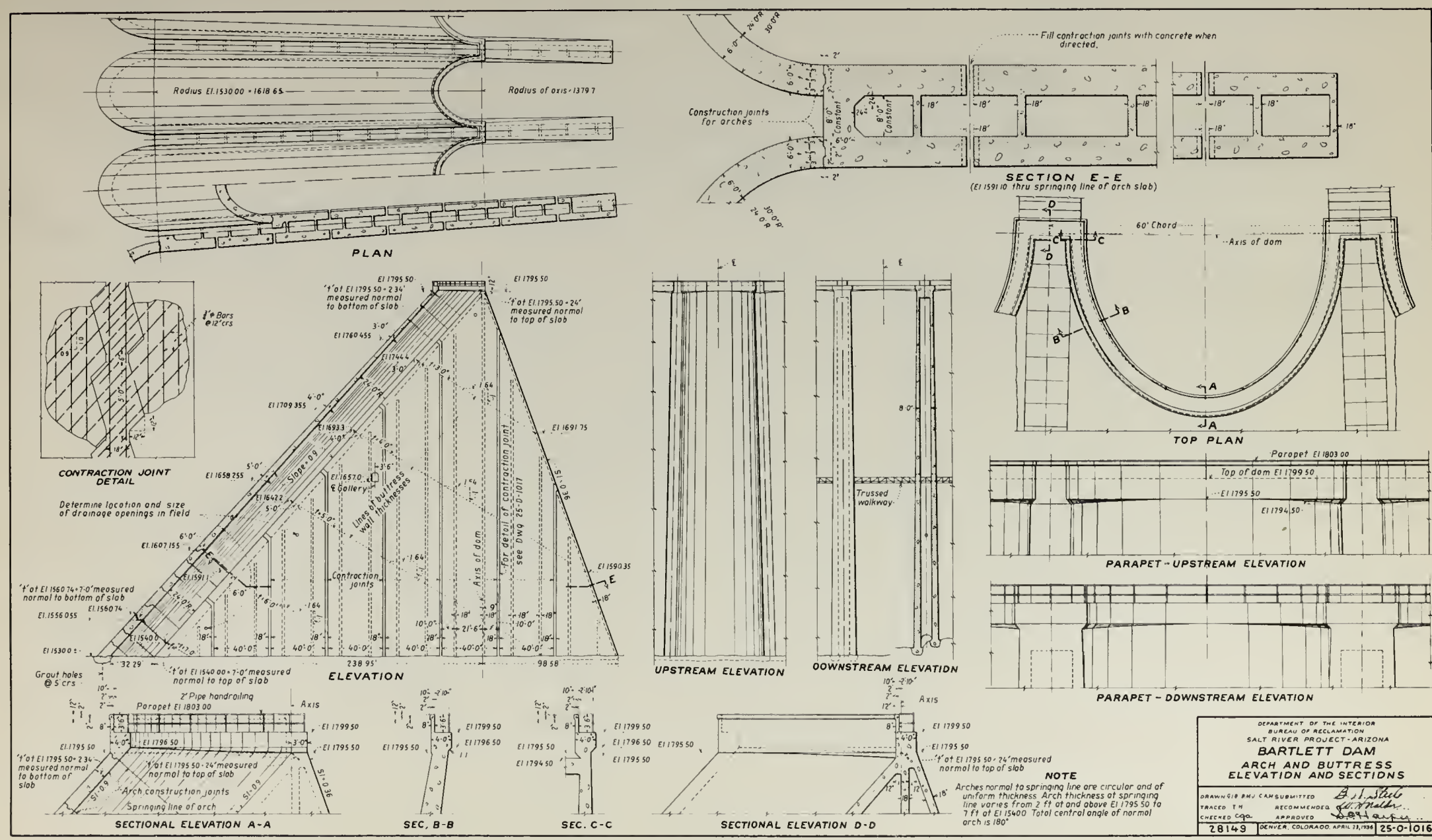


FIG. 8 par. 5.4.18

SECTION AND ELEVATION	BAR NUMBER, SIZE, NUMBER REQUIRED AND SUB-TOTALS FOR EACH LIFT OF 12 FEET																						
	FACE SLAB				BUTTRESS															CUT-OFF		STRUT	
SIZE	1"φ	1"φ	5/8"φ		5/8"φ																	1"φ	5/8"φ
BAR NO	1	2	519		3															7		5	6
LENGTH	15'-0"		19'-0"					504	506	508	510	512	514	516	518	519				15'-0"		16'-6"	6'-6"
								4'-0"	6'-0"	8'-0"	10'-0"	12'-0"	14'-0"	16'-0"	18'-0"	19'-0"							
MISC	REQD	REQD	LGTH	REQD	REQD	SIZE	LGTH	NUMBER REQUIRED												REQD	SIZE	REQD	REQD
846																							
A-A	11	6	15'-0"	9	22	5/8"φ	13'-0"	2	2	0	24	0	4	2	0	8	36	5/8"φ					
834	11			9				2	2	0	24	0	4	2	0	8							
B-B	19	10	15'-0"	9	22	5/8"φ	14'-0"	2	2	2	22	2	12	2	0	18	36	5/8"φ					
822	30			18				4	4	2	46	2	16	4	0	26							
C-C	24	13	16'-0"	9	22	3/4"φ	14'-0"	0	0	2	24	2	22	0	2	28	36	5/8"φ		8	9		
810	54			27				12	4	4	70	4	38	4	2	54				8	9		
D-D	30	15	16'-0"	9	22	1/4"φ	15'-0"	2	2	2	24	2	32	0	2	42	36	5/8"φ					
798	84			36				14	6	6	94	6	70	4	4	96				8	9		
E-E	33	17	16'-0"	9	22	3/8"φ	15'-0"	14	2	2	24	2	40	2	2	56	36	3/4"φ		16	18		
786	117			45				28	8	8	118	8	110	6	6	152				24	27		
F-F	33	17	16'-0"	9	22	3/4"φ	16'-0"	2	2	2	24	2	50	2	2	70	36	3/4"φ					
774	150			54				30	10	10	142	10	160	8	8	222				24	27		
G-G	33	17	17'-0"	9	22	7/8"φ	16'-0"	20	2	2	24	2	60	2	2	84	36	7/8"φ		24	27		
762	183			63				30	12	12	166	12	220	10	10	306				48	54		
H-H	33	17	17'-0"	9	22	1"φ	17'-0"	2	2	2	24	2	70	2	2	98	36	7/8"φ					
750	216			72				32	14	14	190	14	290	12	12	404				48	54		
J-J	33	17	18'-0"	9	22	1"φ	18'-0"	26	2	2	24	2	80	2	2	112	36	1"φ		24	27		
738	249			81				78	16	16	214	16	370	14	14	516				72	81		
K-K	33	17	18'-0"	9	22	1"φ	19'-0"	2	2	2	24	2	90	2	2	126	36	1"φ					
726	282			90				80	18	18	238	18	460	16	16	642				72	81		

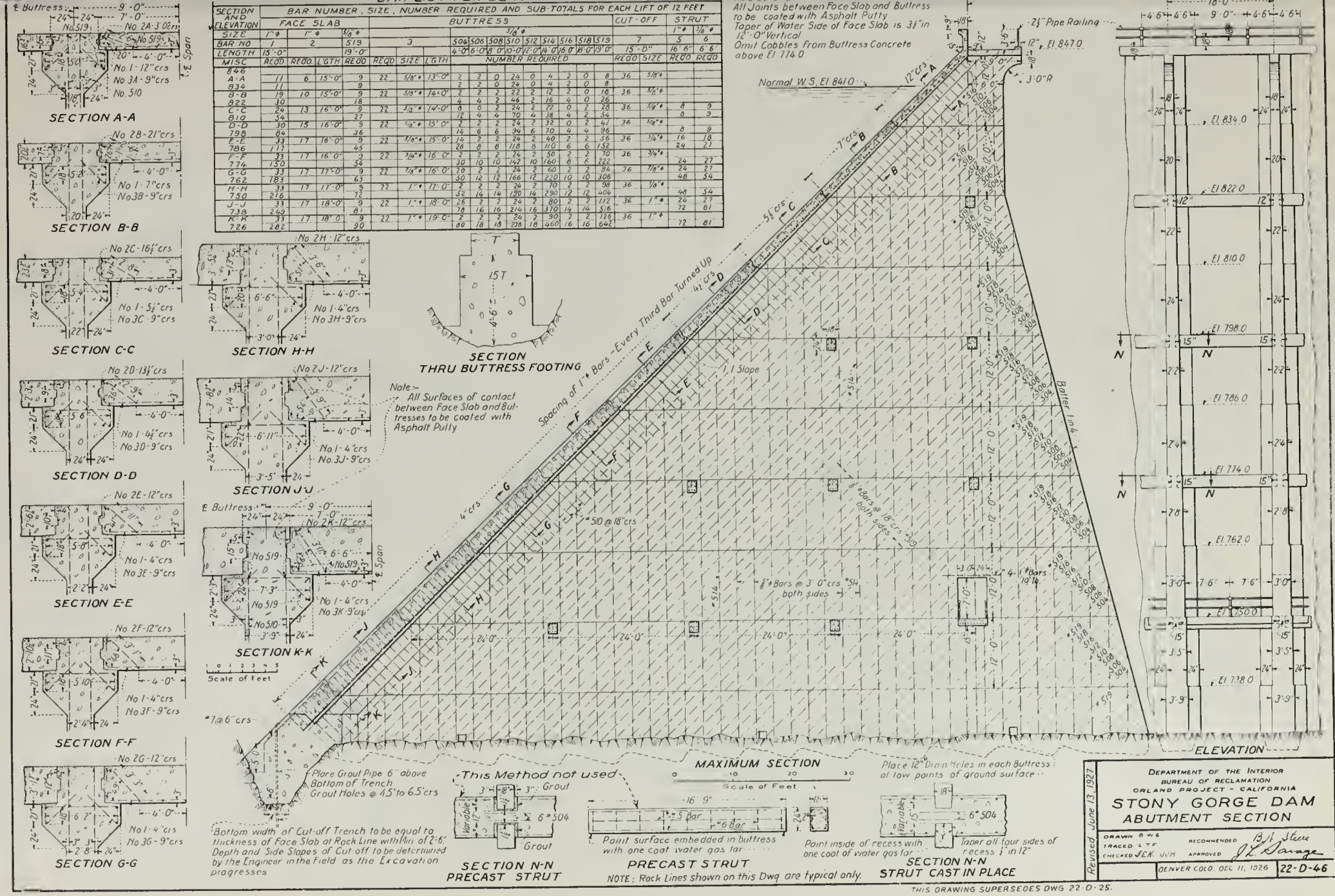


FIG. 9 par. 5 4 18

(.20) pervious foundations, buttresses may rest on a continuous reinforced-concrete mat extending under the entire dam, the bearing capacity of which may be increased in some cases by concrete bearing piles, and the rate of seepage may be reduced by one or more concrete or sheet-pile cut-offs. Such treatment of pervious foundations may produce satisfactory conditions for relatively low dams used for diversion purposes. The design of Imperial Dam on the Colorado River boundary between Arizona and California, as shown in Figure 10, is an example of such treatment. The remainder of this discussion assumes the foundation to be composed of rock formations which can be readily treated to support relatively high buttress dams for storage purposes.

FOUNDATION TREATMENT (CONT.)

.21 Excavation may be divided into two classes: that necessary for buttress footings, and that required for the cut-off wall.

EXCAVATION

A. Excavation for buttress footings consists of the removal of earth and loose rock overburden and the penetration of the underlying rock formation to such a depth as to insure a base capable of withstanding the imposed buttress loads. Depending upon the spacing of buttresses and the required excavation slopes consistent with stable banks, it may not be necessary to remove all the overburden between buttresses. Final shaping of the contact surface between buttress and foundation is carried out as for gravity dams. Downward slopes in a downstream direction are usually avoided.

BUTTRESS FOOTINGS

B. Concrete cut-off walls are usually located at the intersection of the deck with the foundation. Excavation for the cut-off wall will proceed until a foundation rock of adequate bearing capacity and watertightness is secured. All necessary precautions will be taken to preserve the rock below and beyond the lines of excavation in the soundest possible condition. Blasting operations, therefore, will be strictly controlled.

CUT-OFF WALLS

.22 Foundation grouting for buttress dams usually consists of grouting a single row of primary holes drilled below the cut-off wall in order to extend the depth of the seepage barrier. Secondary or relatively shallow holes may be drilled and grouted in order to consolidate and seal surface cracks and seams. Primary grouting is accomplished subsequent to the placing of the cut-off

FOUNDATION GROUTING

(.22) wall by drilling and grouting through pipes extending through the cut-off wall. Secondary grouting may be done before or after the placing of structural concrete. The methods and procedures followed are the same as those discussed for gravity dams.

FOUNDATION DRAINAGE

.23 Foundation drains for buttress dams on rock foundations are usually omitted since the water percolating under the dam can escape between the buttresses without exerting appreciable uplift force. As the buttress footings increase in width, however, weep holes through them may be provided to avoid possibility of developing excessive uplift force. The problem of reducing uplift effects on mat foundations resting on pervious materials may require extensive and complicated drainage systems involving several cut-off walls, ballasted mats, collecting filters, and pumping arrangements.

TEMPERATURE CONTROL

.24 The factors and principles involved in the discussion of temperature control for gravity dams are applicable to buttress dams. Due to the relatively thin structural members of buttress dams, the effect of increased temperatures and accompanying volumetric changes due to heat of hydration is somewhat minimized since much of the excess heat generated is dissipated fairly rapidly from the exposed surfaces. However, the volume change may be large enough to induce tensile stresses which may produce random cracking unless some preventive measures are taken. Such measures usually include restrictions on height of lifts, restrictions on rate of placing lifts, provision for contraction joints, use of low-heat cement, precooling of aggregates, fog-spraying of the surfaces, and use of steel reinforcement. When walls or slabs are five feet or more in thickness, artificial cooling through a single cooling coil placed at the center of the slab may be desirable.

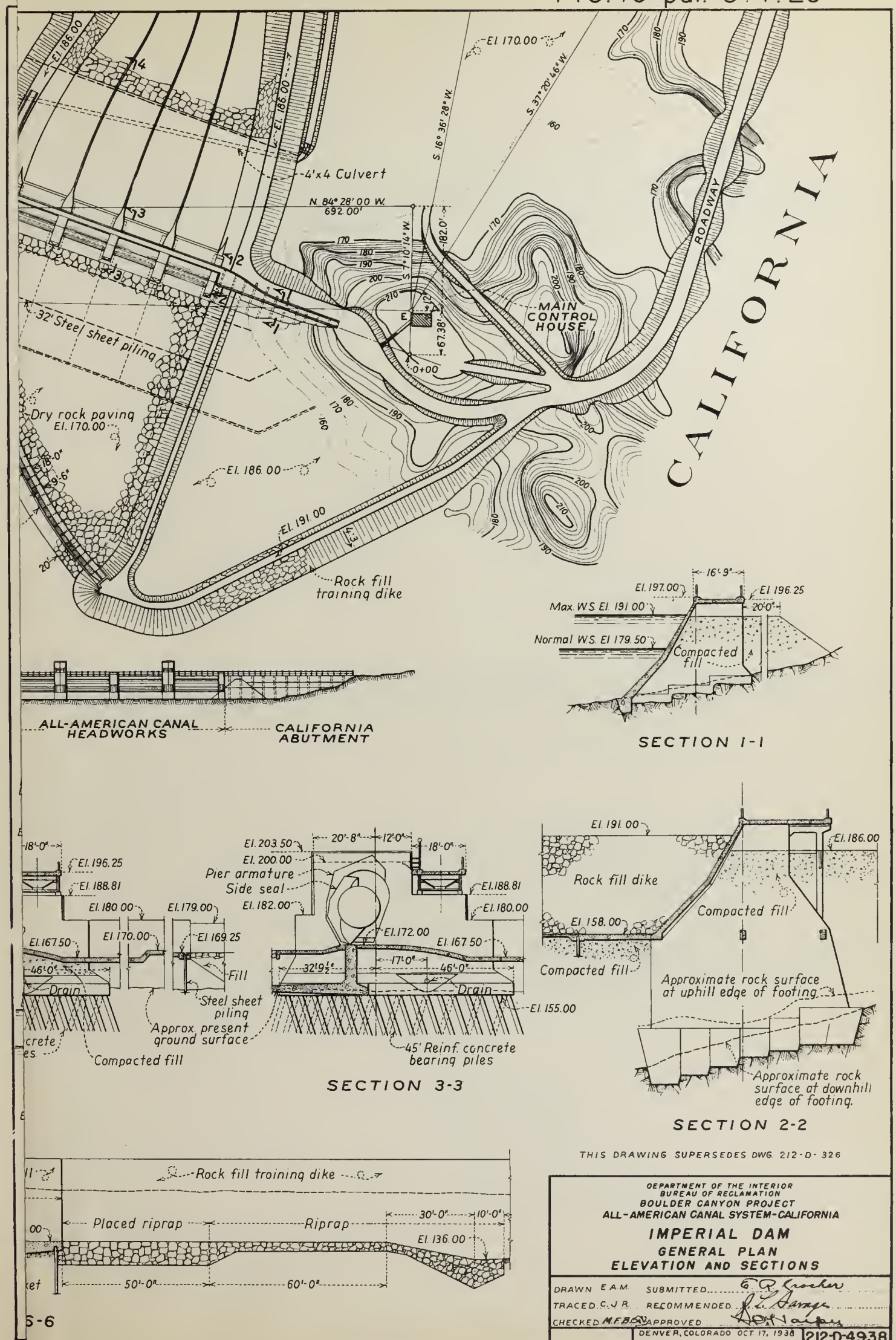
CONTRACTION JOINTS

.25 Contraction joints should be provided whenever the elements of the dam become so large as to make the temperature variations in the concrete during the construction period a major factor in producing cracks, or where the joining of the elements requires articulation allowing freedom of movement.

SLOTS IN BUTTRESSES

A. From the viewpoints of stress distribution and stability, it is desirable that buttresses be so constructed as to form complete unjointed structures. From a shrinkage viewpoint, it is desirable to provide joints at intervals to eliminate the formation

FIG. 10 par. 5.4.20



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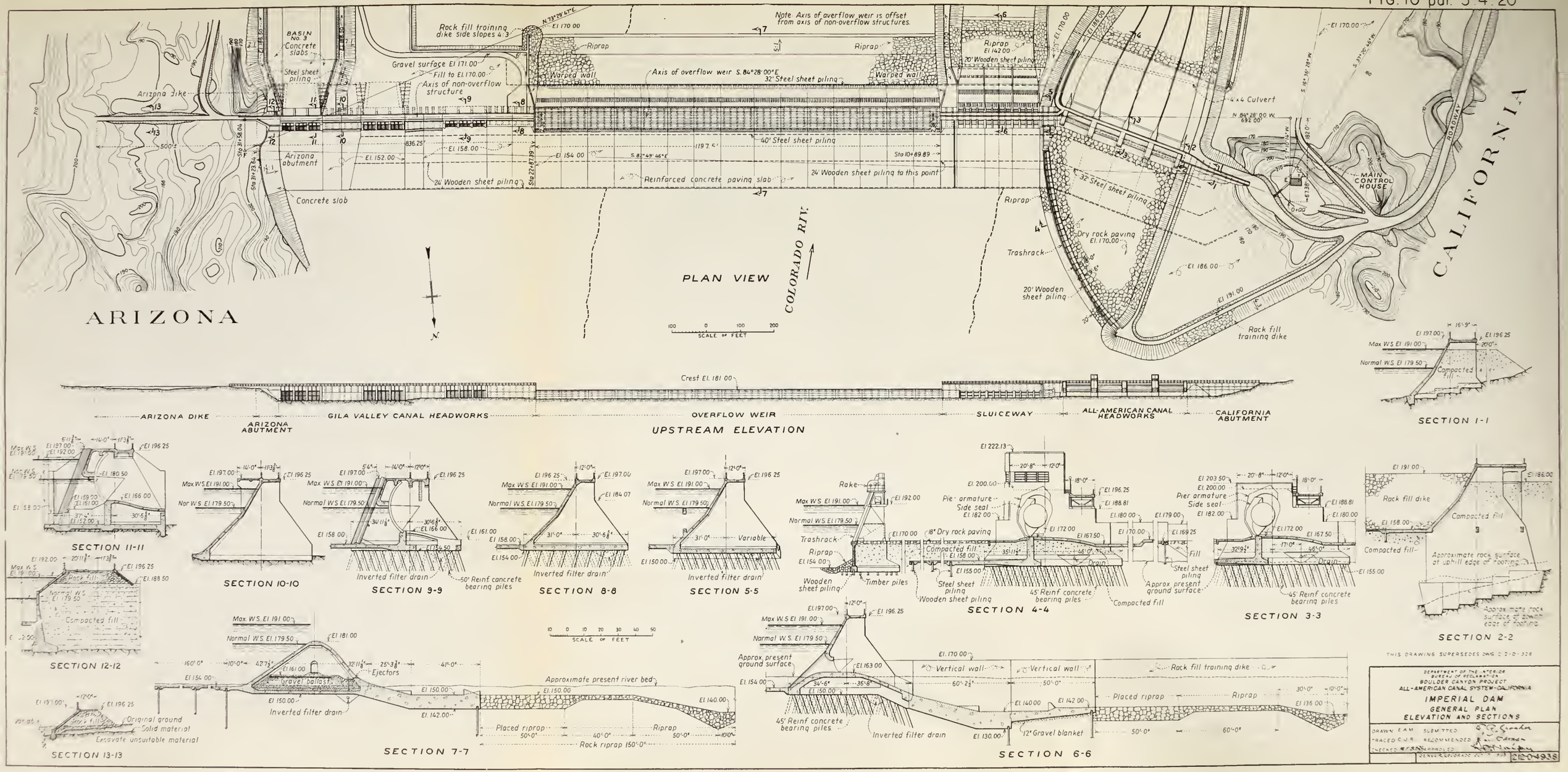
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
ALL-AMERICAN CANAL SYSTEM-CALIFORNIA

IMPERIAL DAM
GENERAL PLAN
ELEVATION AND SECTIONS

DRAWN E.A.M. SUBMITTED E. R. Crocker
TRACED C.J.R. RECOMMENDED J. L. Savage
CHECKED M.F.B.S. APPROVED [signature]
DENVER, COLORADO OCT. 17, 1938 212-D-4938

FIG. 10 par. 5.4.20



(.25A)

of random cracks. In order to satisfy both factors, buttresses may be constructed with vertical open slots placed at intervals of 30 to 50 feet depending upon the degree of temperature control exercised through other measures. Reinforcing steel from each buttress section projects into but does not pass entirely through the slot. Each buttress section is therefore able to undergo its own volume change without restraint from adjacent sections. The width of the slots is such that the length of the steel projecting from adjacent sections is sufficient to develop its strength in bond. When each section has reached its final stable volume, the slots are filled with concrete thereby tying all sections together. Any further reduction in volume due to seasonal temperature variations will be resisted by the reinforcing steel. Details of buttress contraction slots, as used in the construction of Bartlett Dam, are illustrated in Figure 8.

SLOTS IN BUTTRESSES (CONT.)

B. In flat-slab dams, contraction joints are provided at the contact surface between the deck and buttress in order to permit separate structural action of the elements and also to allow for the expansion and contraction of the deck due to seasonal temperature variations. In relatively high dams of this type, horizontal contraction joints may also be provided at intervals in the deck slab in order to prevent the accumulated expansion or contraction from being concentrated at the top of the dam.

JOINTS IN FLAT SLABS

.26 Concrete placing operations are regulated in order to conform to the requirements of temperature control and structural stability during the construction period.

CONCRETE PLACING

A. The height of lifts is usually restricted to approximately 10 feet in the buttresses, and 15 feet, measured along the slope of the upstream face, in deck slabs and arch barrels. No lift of the deck should be placed until all the concrete of the buttresses supporting that lift has developed sufficient strength to carry the imposed load.

HEIGHT OF LIFT

B. Since the water-supporting member of buttress dams is relatively thin, thereby presenting a short path of percolation, it is desirable to provide a concrete which possesses as great a degree of imperviousness as practicable. This may be achieved by imposing strict, laboratory-controlled measures on the manufacture of

IMPERVIOUS MIX

(.26B)

the concrete, by carefully working and compacting the concrete during the placing operation, and by using an absorptive form lining or vacuum process to remove excess moisture from the surface concrete.

SURFACE CLEAN-UP

C. Careful preparation of the surfaces of each lift before placing succeeding lifts must be accomplished. Such operations are discussed in Chapter 5.2.

SEALS

.27 In order to provide a watertight joint at the contact surface between flat-slab decks and buttresses, the surface is usually covered with some type of heavy mastic material, such as asphaltic putty, before placing the deck slab. Similar treatment is usually given to horizontal contraction joints in the flat-slab deck. Additional watertightness may be obtained in these latter joints by the use of additional M-type metal seals. Special joints between the dam and appurtenant structures which must allow maximum flexibility and still remain watertight may require special rubber seals as used in the construction of Imperial Dam between the deck and the upstream apron.

STAIRWAYS AND WALKWAYS

.28 Stairways and walkways are provided within a buttress dam both to give access to controls for reservoir operation and to permit close inspection and repair of the underside of the deck and the buttress walls. Either concrete or metal stairways are usually placed along a buttress wall. Walkways between buttresses may be supported by bracing struts, beams or trusses, and are usually of steel construction.

BUTTRESS OPENINGS

.29 Walkway openings through the buttresses should be as small as practicable. The top of the opening should be circular and the buttress area surrounding the opening should be heavily reinforced. Openings should be placed away from contraction joints. It may be necessary also to provide small openings through the buttress to permit equalization of the backwater pressure on both sides. This applies particularly to a double-wall buttress. Stiffener walls in double-wall buttresses should also have equalizer openings.

OUTLET WORKS

.30 When outlets are provided through buttress dams, considerations for their design are similar to those discussed in Chapter 5.2. Further consideration, however, should be given to the proper anchoring of both ends of the conduit and to the intermediate conduit supports.

.1 There are substantial advantages to be gained from the use of public hearings as a means of gaging public opinion and interest in the development of Reclamation projects. The procedure prescribed herein for the holding of such public hearings contemplates that the hearings will be conducted on a formal basis. It is not intended to preclude discussions on an informal basis with select, small groups, such as an interested group of water users, prior to, during, or after completion of an investigation, but the purpose of such discussions is primarily to arouse or maintain interest in the development as it progresses, to secure cooperation, or to allay fears. Results of informal meetings cannot be given the formal recognition granted public hearings. CHAPTER CONTENT

.2 Primarily, this type of public hearings is held to explore local public reaction to plans contemplated by the Bureau, and to determine the willingness of those affected to cooperate under the Reclamation Laws in their development, and the conditions under which such cooperation could be most advantageously attained. Hearings permit local interests to have first-hand knowledge of plans and allow them opportunities for discussion; and, in addition, present full opportunity for obtaining the views of state and Federal agencies and of other groups while the reports are in a formative status. PURPOSE

.3 The determination of the need for a public hearing and the holding of such hearings shall be entirely within the discretion of the Regional Director, but district or field office officials shall be responsible for keeping the Regional Director advised of local events and public sentiment at all times. DETERMINATION OF NEED

.4 Generally, hearings on development plans should be held only after investigations have progressed sufficiently to indicate clearly the possibilities for, and characteristics of, the development under consideration, i.e., after completion of the preliminary draft of the report. Where intricate plans are involved, especially those requiring collaboration of several interests in multiple or joint use features, it may be desirable to prepare and disseminate specially prepared descriptive reports in order to give local interests and participating agencies full opportunity to acquaint themselves with details of the plans to be discussed prior to the date of the hearing. It may sometimes be desirable, however, to hold a public hearing prior to initiation of investigation of a project to determine if local opposition or lack of interest would render it unacceptable even if investigation proved it economically justifiable and engineeringly feasible. Preinvestigation hearings should not be held unless the Bureau is prepared to proceed immediately with the investigation provided the hearing indicates favorable public interest. TIMING

.5 The sample form shown as Illustration 1 shall be followed in the preparation of Notices of Public Hearings, with such deviations in terminology and additional provisions as may be required to cover specific situations. All Notices of Public Hearings shall be issued and signed by the Regional Director. The notice itself should be confined to one side of a single sheet. On the reverse side it may be desirable to list in more detail the information desired from those who will attend the hearing. A map on the reverse side of the notice showing development possibilities under consideration will often be of value. In the notice itself or in elaborating materials the term "proposed" should not be used in reference to any projects or works under study. Generally such projects or works should be referred to as "projects being considered" or "development possibilities," or equivalent. FORM OF NOTICE

.6 Distribution of notices for public hearings shall be made by the Regional Director as far in advance of the date set as possible. Copies shall be mailed direct to the following officials of Federal agencies in Washington, D.C.: CIRCULATION OF NOTICES

Chief of Engineers, Corps of Engineers, War Department	5 copies
Chairman, Federal Power Commission	4 copies
Land Use Coordinator, Department of Agriculture	7 copies

CIRCULATION OF NOTICES (Cont.)

Commissioner, Bureau of Reclamation 25 copies
(The Commissioner's office will distribute copies to other Department of the Interior agencies in Washington through the Water Resources Committee).

Distribution of notices to other interested agencies and groups should include: field offices of Department of the Interior agencies and of other Federal agencies; appropriate Congressmen; appropriate state officials; appropriate county and city officials; newspapers; post offices; reclamation associations; irrigation and utility districts; cooperatives; and individuals and other groups as appropriate.

PRESS RELEASES

.7 Notices of public hearings sent to newspapers generally should be accompanied by a press release, which states in news form and in nontechnical language, the purpose of the hearing. Such press release should point out the advantages of the project and generally outline the problems of public policy that are involved in connection with its construction. The release should be distributed to newspapers as early as possible to prepare those who attend the meeting with a preliminary understanding, which will lead to intelligent discussion and to increase the probability of accurate news articles being prepared in relation to the meetings.

CONDUCT OF HEARINGS

.8 The Regional Director or any responsible subordinate he may designate shall conduct public hearings. The person selected to conduct the hearing should have full knowledge about the area and the plan of development. He must be able to present data and participate in all discussions in a forceful manner. Ample opportunity shall be given to other Department of the Interior agencies to indicate subjects to be brought up and discussed at the hearing and to participate in the hearing. A transcribed record and list of attendance at all hearings shall be kept, and five copies thereof shall be submitted to the Commissioner with the final report of the Regional Director, as an appendix to the report.

COOPERATION WITH OTHER AGENCIES

.9 It is desired that the Regional Director provide full opportunity for representatives of other Federal agencies to participate in public hearings. However, should the interests of such agencies require an extension of the hearing beyond the limits considered sufficient for the purposes of the Department of the Interior, the additional expense of such extensions, or possibly additional hearings, should rest with these agencies. In some instances it may be desirable to hold a joint hearing in which case the Notice of Public Hearing should be so worded and should be signed by both the Regional Director and the appropriate representative of the participating agency.

UNITED STATES
DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Region 1

P. O. Box 937, Sonna Building
912 Main St., Boise, Idaho

February 18, 1940

NOTICE OF PUBLIC HEARING

A public hearing in connection with irrigation and related land and water resources development of the Spring River Watershed, Oregon, will be held in the City Hall, Corvallis, Oregon, at 10:00 a.m., on Tuesday, March 19, 1940.

This hearing will be held to obtain information to supplement that being obtained in the current investigation of the Spring River Watershed and to permit the Bureau of Reclamation to outline and explain the plan as now contemplated by the Bureau. Information is desired particularly on the sentiment of local interests concerning development of new irrigation in the Spring River Watershed and their cooperation in such development under the Reclamation Laws. The map on the reverse side of this sheet indicates the primary structures and areas tentatively being considered for development.

All interested parties are invited to be present or to be represented at the above time and place. All will be given opportunity to express their views on improvements desired or under consideration.

Oral statements will be heard, but for accuracy of record, important facts or arguments should be submitted in writing, as the records of the hearing will be forwarded for consideration by the Department of the Interior. Written statements may be handed to the undersigned at the hearing or mailed to him beforehand.

Your cooperation in communicating the foregoing to any persons known by you to be interested in the water and land resources development of the Spring River Watershed will be appreciated.

R. J. Newell,
Regional Director.

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CHAP. 6.2 HEARINGS HELD BY OTHER AGENCIES

CHAPTER CONTENT

.1 District Engineers of the Corps of Engineers frequently hold public hearings on investigations and proposals for flood control and rivers and harbors improvements. This chapter sets down procedures for handling notices of these hearings and reports on those hearings that concern the Bureau.

NOTICES OF PUBLIC HEARING

.2 Ordinarily, the District Engineer of the Corps of Engineers will send a copy of the Notice of Public Hearing to the Regional Director concerned if he feels that the Bureau is interested. In addition, the District Engineer sends copies of all Notices to the Secretary of the Interior, and these are referred to the Director, Branch of Project Planning, in Washington. In order to make certain that the Regional Director is informed of all public hearings, the Director, Branch of Project Planning, will send a copy of each Notice of Public Hearing received, to the appropriate Regional Director, without a letter of transmittal.

BUREAU REPRESENTATION

.3 The Regional Director shall determine whether the Bureau is interested in the hearing, and if it is, shall send a competent representative to the hearing.

REPORT ON HEARINGS ATTENDED

.4 Promptly after each hearing attended by a representative of the Bureau, the Regional Director shall forward a report to the Commissioner covering all important facts which were developed at the hearing, or related to it.

PARTICIPATION BY REGIONAL DIRECTOR

.5 When invited to participate in public hearings initiated by the Corps of Engineers or other Federal, state or local agencies, the Regional Director shall accept the invitation, if it is to the interest of the Bureau to do so, and shall participate to the extent deemed appropriate by him.

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UNITED STATES
DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Washington 25, D. C.

Approved: Sept. 28, 1951		VOLUME III BASIN AND PROJECT DEVELOPMENT ADVANCE SUPPLEMENT NO. 1
Effective: Upon receipt	RECLAMATION MANUAL	
Received:		

1. Advance Supplements No. 1 for each of Volumes XIII and XV of the Manual explained the adoption of the new price level for use in economic analyses. The general level of the new price projections for agricultural products is 215 (1910-14 equals 100) or approximately 50 percent higher than the 1939-44 price level. This, of course, will affect the selection of potential reclamation units and projects, and accordingly, Paragraphs 3.1.5F to 3.1.5K inclusive, of Volume III, are hereby superseded by the following, and a new paragraph on "Construction Cost Estimates" is added:

F. All construction cost estimates will be based on current costs. — CONSTRUCTION COST ESTIMATES

G. The estimated revenues from all project sources should be sufficient to pay for all reimbursable costs, in addition to operation, maintenance, and replacement costs. The costs used in estimating power revenues will be based on current prices; all other repayment studies will be based on a level comparable to 215 (1910-14 equals 100) for agricultural prices. (See Volume XV). — REPAYMENT

H. Total project benefits must equal or exceed total project costs. (See Volume XIII). Sometimes the project with the highest benefit-cost ratio is selected in preference to a more extended project with a lower ratio. Normally, however, the principle of maximum net benefits as the ultimate objective should rule. The level of prices used in the benefit-cost analyses for power features will be current prices; all other features will use a level of prices comparable to 215 (1910-14 equals 100) for agricultural prices. — BENEFIT-COST RATIO

I. The extent of development should be determined by the point at which the net benefits are at a maximum, or most nearly so as determined by some practical measurement. Net benefits are considered to be maximum when the extent of development is at the point where the benefits added by the last increment of the project scope are equal to the costs of adding that increment. — SCOPE

J. All selected projects must be able to meet operation, maintenance, and replacement costs, as a minimum. The level of prices to be used for estimating operation, maintenance, and replacement charges for separable power features and for the share of joint features chargeable to power will be based on current prices and costs. The level of prices to be used for estimating operation, maintenance, and replacement charges for all other separable features and shares of joint features will be based on a level comparable to 215 (1910-14 equals 100) for agricultural prices. — O&M & REPLACEMENT

K. Maximum feasible power development, consistent with other priority of uses, is a requirement. — POWER DEVELOPMENT

L. The selected multiple-purpose units or projects should be more economical of development as a whole than other potential means for accomplishing the same aggregate benefits. — ECONOMY OF DEVELOPMENT

(Sgd.) Michael W. Straus
Commissioner.

Distribution: III

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Urbana, Illinois

UNITED STATES
DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Washington 25, D. C.

Approved: May 14, 1953 **Effective:** Upon receipt **Received:**	RECLAMATION MANUAL	VOLUME III BASIN AND PROJECT DEVELOPMENT RELEASE NO. 25

1. MATERIAL TRANSMITTED:

To reduce the number of Transmittal Sheets retained with each Volume of the Manual, periodic Summary Transmittal Sheets will be issued. This, the first for Volume III, is a tabulation of all material still in effect from Releases 8 through 24. The Transmittal Sheets for these releases now on file shall be removed and destroyed, provided that one set shall be maintained in each Regional Office, and elsewhere at the discretion of Regional Directors, in accordance with Paragraph 7.4.22 of Volume I.

This sheet, together with Transmittal Sheets subsequently issued, may be used in checking the completeness and currency of Volume III material on file at any time.

Pages	Date	Rel. No.	No. Sheets	Pages	Date	Rel. No.	No. Sheets
Table of Contents	1/11/51	22	1	4.2.15	3/22/49	8	1
1.1.1 - 1.1.15	3/22/49	8	3	4.3.1 - 4.3.8			
1.2.1 - 1.2.13F	3/22/49	8	3	& Illus. 1	4/13/50	13	5
2.1.1	5/2/50	14)		Illus. 2	7/28/49	9	1
2.1.4	7/19/50	17)	1	4.4.1	6/23/50	15	1
2.2.1 - 2.2.11	3/22/49	8	4	4.5.1	3/22/49	8	1
2.3.1 - 2.3.3B	3/22/49	8	1	4.6.1	3/22/49	8	1
2.4.1 - 2.4.2L	9/1/50	19	1	4.7.1 - 4.7.10A	3/22/49	8	2
3.1.1 - 3.1.6A	9/13/50	20	2	4.8.1	3/22/49	8)	
4.1.1 - 4.1.2D	3/22/49	8	1	4.8.4	8/21/50	18)	1
4.2.1 - 4.2.4	3/22/49	8	1	4.9.1 - 4.9.20C	1/30/50	11	4
4.2.5D - 4.2.5G	1/25/51	23	1	Illus. 1	3/22/49	8	1
4.2.6 - 4.2.9A	3/22/49	8	1	4.10.1 - 4.10.21A	10/31/51	24	2
4.2.9B - 4.2.9C	1/25/51	23	1	5.1.1 - 5.1.6	3/2/50	12	1
4.2.9D	1/25/51	23)	1	6.1.1 - 6.1.7			
4.2.9E	3/22/49	8)		& Illus. 1	3/22/49	8	2
4.2.9F - 4.2.9L	3/22/49	8	2	6.2.1	3/22/49	8	1
4.2.9-O	1/4/50	10)	1				
4.2.9R	11/28/50	21)					

The material described above was modified by the following pen and ink changes:

Change	Rel. No.	Date
Former Chapter 1.3 renumbered 1.2	22	1/11/51
Table of Contents - title of Chapter 2.4 changed to "General Engineering and Research"	23	1/25/51

Advance Supplements 1, 2, and 3 are effective.

1 Je 53

2. ORIGIN AND CLEARANCE:

This release was prepared by the Project Planning Division and was reviewed by the Office of Management Planning.

Fred G. Aandahl
Assistant Secretary - Water and Power

Distribution: III

Interior - Reclamation - Denver, Colo.

Vol. IV 1.1 - 6.3

VOL

4

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION MANUAL

Volume IV Water Studies

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Rel.42 1/19/51
Supersedes 12/30/47

CHAP. 1.1 IMPORTANCE OF WATER IN WESTERN ECONOMY 1.1.1

.1 Water, land, and climate are the basic natural resources for an agricultural economy. In the western United States, land is abundant and relatively fertile. Climatic conditions, including temperature distribution and amount of sunlight, are especially favorable to many crops. Water is the limiting factor. Precipitation during the growing season is generally deficient for effective crop growth over essentially all agricultural lands west of the 100th meridian, and in many years poorly distributed in the adjacent areas to the East. Precipitation from the Rocky Mountains westward occurs principally during the winter months, much of it in the form of snow which melts and runs off during the early spring months. Diversion of this streamflow for irrigation of the land is essential to the growing of nearly all crops. Small grains are grown without irrigation in areas of higher precipitation, but summer fallowing to conserve moisture and fertility from 1 year to the next is a common practice. WESTERN AGRICULTURE

.2 The progress of western settlement has been governed by opportunities for development of resources and, to some extent, by the enjoyment of climatic advantages. Early settlements were made near streams, where opportunities for navigation and power were available, but the availability of domestic water supplies has in many cases been a controlling factor and the availability of irrigation water has been a major factor in many instances. For example, Boise, Idaho, and Phoenix, Arizona, state capitols and major cities in their respective states, owe their existence almost entirely to irrigation; and the growth of such cities as Denver, Colorado, Salt Lake City, Utah, Sacramento, California, Albuquerque, New Mexico, and El Paso, Texas, has been greatly influenced by irrigation development. DEVELOPMENT

.3 The influence of irrigation has been especially beneficial to the economical use of adjacent range lands. Livestock, grazed on public and private range lands during the summer months, are fattened or carried through the winter months on hay and grain produced on irrigated ranches. In other cases irrigated pastures supplement short season mountain ranges during the spring and fall months. IRRIGATION IN REGIONAL ECONOMY

.4 Early planning in the West took little account of the future. Water was utilized from the most convenient sources and those sources were over appropriated before plans were made to develop the surplus flows of less readily accessible streams. Frequently development exceeded local supplies with resultant conflict between rival users, and physical and financial losses to all when overtaxed supplies failed. These difficulties have produced many innovations in western life. The physical and financial inability of individual irrigators to develop the more difficult projects led to the formation of irrigation corporations and districts in order to amass sufficient capital to employ technical assistance and to construct expensive works. Some of these, on reaching their financial limits, have appealed for and received, state and national aid through loans and technical services. The Federal Reclamation Laws were enacted to aid the settlement of the West by farm-owner operators. Individual towns and cities, on exhaustion of local supplies, have gone far afield for supplementary supplies, as witnessed by the Los Angeles diversion from the Owens Valley, and the Denver diversions from the Colorado River Basin. When costs exceeded the ability of smaller cities, metropolitan water districts, such as that now operating a great aqueduct system in southern California, were organized to obtain greater revenue. At present the Bureau of Reclamation, with the cooperation of other Federal agencies, is planning development on a basin-wide basis to obtain the most advantageous use of available water resources. This is paralleled by studies of possible transbasin diversions further to bring surplus water and undeveloped land or thirsty cities together. EXPANSION

.5 Western development has produced a new order of water law. The older system of riparian right to an undiminished and unchanged stream has given way to the appropriative doctrine of beneficial use predicated on the premise of first in use as first in right. Disputes between individuals have inspired state water laws and judicial decrees to settle those disputes. Conflicts between water users of different states and with Canadian and Mexican neighbors have engendered interstate compacts and international treaties, establishing the basis LEGAL CONCEPTS

for equitable divisions. In many states municipal and domestic supplies have been accorded a preferential use with irrigation second, followed by hydroelectric power and navigation. The overdevelopment of underground water has, in some states, led to the formulation of underground water laws to protect prior appropriators and to restrict pumping to safe recharge rates.

LIMITS OF DEVELOPMENT

.6 Water, tritely but truly, has been called the life blood of the West. When the ultimate feasible regulation of western water supplies has been reached, the measure of western development will be taken. Thereafter, development will be confined to seeking a balance among domestic needs, agriculture, and industry.

CHAPTER CONTENT

.7 The foregoing general discussion gives no specific directions for treatment of problems, but is intended to stimulate an awareness of the importance of water to western life in the formulation of adequate project plans.

CHAP. 1.2 THE HYDROLOGIC CYCLE

THE CYCLE

.1 The hydrologic cycle is the circulation of water through physical processes from the sea to the atmosphere, to the land, and return to the sea. It begins with evaporation. The water vapor, through convection, rises into the air, condenses in clouds which are transported by winds under influences of unequal temperatures and the earth's rotation, and finally precipitates in the processes of cooling as it rises over mountains or in contact with masses of cold air, as rain, snow, or hail. That part falling as snow during winter months is retained in storage until it is melted by insolation or rising air temperatures in the spring to join with rainwater in motion under the forces of gravity collecting as surface streamflow or as groundwater percolation later appearing through springs or wells as surface flow. In movement it is subject to retention in surface lakes or underground basins. It is reduced by evaporation and transpiration or tissue building of plants. The residue not consumed in transit returns eventually to the sea carrying with it dissolved and suspended solids from the earth.

APPLICATION

.2 An understanding of every phase of this cycle is indispensable to the hydrologist or engineer engaged in planning, designing, constructing, and operating works for the control or utilization of water for the many benefits water can afford to man. He utilizes his knowledge of the static and dynamic forces of the various phases of the hydrologic cycle, to anticipate the occurrence of water as rain, and forecasts the amount of its runoff in flood. He estimates its loss by evaporation, transpiration, and seepage. He applies his knowledge of the cycle in designing dams to impound water in flood for later use in periods of drought. He plans conduits to convey it from streams or lakes to distant points of use, powerplants to convert its energy to useful work, and pumps to lift it to higher levels. He provides water artificially for the irrigation of dry soil to produce vegetable food and fiber for the sustenance of life and its protection from the elements. Subsequent sections of the Manual are concerned with the details of this utilization and the allied problems, physical and cultural, associated with it.

CHAP. 1.3 WATER SUPPLY INVESTIGATIONS

SCOPE OF INVESTIGATIONS

.1 Water supply investigations and studies involve the determination of the source, extent, character, and dependability of water resources; the analyses of present and past utilization of water supplies; and the evaluation of future opportunities for their control and development. Water supply investigations are as essential to the development of a project plan as economic studies are to utilization. They fix basic requirements for the design, construction, and operation of project works. Because interest in water is universal and the uses of water are manifold, water supply investigations are of many types. When interests compete or conflict, investigations must be sufficiently broad to cover all pertinent phases and problems.

RESOURCE SURVEYS

.2 The simplest type of water supply investigation is the evaluation of water resources. Investigations of this type, usually made by the Federal Government or by state governments, are primarily factual. They consist of continued measurements of streamflow or groundwater elevations as they occur. The primary concern is an adequate coverage of all significant sources of supply at points of present or anticipated future interest, to acceptable standards of accuracy in consideration of possible future uses.

RECONSTRUCTED FLOWS

.3 A second type of study goes beyond the determination of historical flows by attempting to reconstruct flows under specified conditions of use. Undepleted conditions are especially important for physical analyses, such as natural relations between rainfall or snow melt and runoff, or correlation of runoff on different watersheds. The undepleted flow may also be required as a basis for division of water among competing interests or for estimating runoff behavior under some special condition. Reconstruction is accomplished by correcting flow for all modifying influences, such as storage regulation and storage losses, consumptive uses or diversions, as they have occurred, in order to represent the undisturbed natural flow. Similarly, flows may be reconstructed to represent any other desired condition, such as the present, or some definite past or future condition. Modifications may be made by adjusting historical flows for the differences in depletions between those existing or assumed for the condition desired and those under historical conditions or by applying the total modification for the desired condition to the undepleted condition. The method to adopt varies with the situation. For studies extending over many years on streams that have experienced a continuing development, it is usually advisable first to convert to undepleted flow conditions and then apply all the modifying influences consistent with the condition desired. If there has been no appreciable change in conditions during a period of critical flow, whether high or low depending upon the nature of the investigation, it is sufficient to modify historical flows for the changes anticipated to follow with the contemplated development. It is important in such studies to allow for modification in natural channel losses or evaporation, as well as the changes effected by storage regulation and losses, diversions or depletions, and return flows. The principles to be followed in Bureau studies are covered in other chapters of this Volume.

PROJECT STUDIES

.4 Project water supply studies employ the same techniques as are used in reconstructing flows. In project studies, however, interest is centered not so much upon the modified flow as upon the means used to accomplish it. Investigations consist of comparing the results to be obtained with structures of different sizes or design, or with different demands, seeking the most efficient, economical, or desirable plan for utilizing the water resources. The end results are compared in terms of costs and benefits as measured by firm and secondary electrical energy produced in kilowatts of capability or kilowatt-hours of electrical energy, irrigation water yield in acre-feet or acres served, flood control in reduction of peak discharge or area inundated, navigation in increased stage during critical months, control of sediment accumulation, and other project purposes. It is necessary in final studies, especially for multiple-purpose or joint use projects where a gain for one function may represent a loss for another, to convert all results to a common monetary denominator. While many studies are required in the process of trial and error to reach a decision the

final study, representing operation of the adopted plan, is frequently the only one to appear in planning reports. It is usually carried out to show the reconstructed conditions, as well as the project performance.

INTER-RELATED INVESTI-GATIONS

.5 Water supply studies are not confined to hydrology alone, but are related to many branches of engineering, economics, agriculture, and related sciences, especially where overall basin investigations and multiple-purpose projects are involved. Hence, water supply investigations must be properly coordinated with field surveys, with land classification, with comparative designs and estimates, and with alternative plans in order to achieve the most beneficial solution.

FORMS FOR WATER SUPPLY STUDIES

.6 There are numerous standard forms and graphs designed to facilitate the preparation of water supply studies and the tabulation of data, or which are adaptable to this use. Forms and graphs are generally available for performing all standard types of studies, and many specialized studies, but it may be necessary to improvise forms applicable to the particular studies being made. Forms are usually 8" x 10½", or 10½" x 17" to 20", which facilitates binding with other data. When it is necessary to improvise forms, it is desirable to make them of standard dimensions. Regional offices shall keep field offices advised of the availability of such forms. For other operational forms, see Chapters 2.4 and 2.5 of Volume XVI.

A. The Water Supply forms listed below are available through normal supply channels (see Volume XIX). Samples of these forms are available for review in all regional offices and in most field offices.

Form No.	Description
7-176	Observation of River Height--franked postal card (July 1936)
7-192	Gage height and discharge, daily (Jan.-Dec. yr.) (11" x 17") (Bond or manifold) (Jan. 1937)
7-192a	Gage height and discharge, daily (Oct.-Sept. yr.) (11" x 17") (Bond or manifold) (Oct. 1936)
7-196	Section diagram, water user record (April 1936)
7-207	Discharge Measurements (May 1937)
7-208	Discharge Measurement Notes (Sept. 1943)
7-210	Rating table (Oct. 1936)
7-212	Daily Gage Height or Discharge, year sheet (calendar year) (January 1937)
7-213	Daily Gage Height or Discharge, year sheet (Oct.-Sept. yr.) (Feb. 1938)
7-214	Gurley Gage Height Record (Jan. 1936)
7-215	Cross Section sheet (10" x 10" to 1") (April 1937)
7-216	Report on River Stations
7-221	Rating Curve (11" x 17") (May 1938)
7-223	Hydrographic Discharge Data (calendar year) (March 1937)
7-223a	Hydrographic Discharge Data (Oct.-Sept. year) (March 1937)
7-230	Daily record sheet (one year) (June 1937)
7-269a	Level Notes--Stream Measurement (5"x 8" punched)
7-270	Canal Cross-Section Book
7-275	Current Meter Notes
7-275b	Discharge Measurement Notes, Two-table Method
7-275c	Discharge Measurement Notes
7-275d	Supplementary Discharge Measurement Notes
7-330	Weather Conditions
7-1264	Hydrographic (10½" x 20") (Oct.-Sept.)
DI-8	Observations of Gage Height (4" x 6") Book
HD3	Probability tabulations and computations (8" x 10½")

FORMS FOR WATER SUPPLY STUDIES (Cont.)

Form No.	Description
HD6	Runoff, monthly (8" x 10½")
HD7	Envelope Curve Data--Peaks and Volumes (8" x 10½")
HD10	Design Flood (8" x 10½")
HD25	Period of Streamflow record (for bar diagrams) (10" x 18")

B. Graph paper is listed in Book 1, Samples, Bureau Forms, and is listed and illustrated in the catalogs of various companies which sell engineering supplies and drafting materials.

CHAP. 1.4 COOPERATIVE AGREEMENTS WITH OTHER AGENCIES

GENERAL POLICY

.1 It is the policy and practice of the Bureau of Reclamation to cooperate with other agencies of the Federal Government, and with state and local agencies in conducting project planning investigations. This policy is applicable to the collection of physical data concerning water as it permits economical operation by those agencies specializing in particular fields without duplication of effort and competition for funds. Where a transfer of funds is involved, Section 7(a) of the Economy Act of 1932 (31 U.S.C. 686), as amended, sets out the standards that must normally be adhered to and provides the machinery by which the transfer is made. Special provision for transfers to the Geological Survey are made in the Interior Department Appropriation Act and to the Fish and Wildlife Service in the Act of August 14, 1946 (60 Stat. 1080). The Act applies to materials, supplies, equipment, work, or services. Cooperation may be entirely informal through free exchange of information, or by formal memorandum of understanding providing for specific items to be prepaid or reimbursed by a transfer of funds.

MISSOURI RIVER BASIN PROJECT

.2 The ★1946 and subsequent★ Interior Department Appropriation Acts appropriating funds to the Bureau of Reclamation for the partial accomplishment of the authorized works of the Missouri River Basin Project contain the provision that the appropriation "shall be expended, either independently or through or in cooperation with existing Federal and state agencies." This provision permits transfer of funds to other agencies for appropriate work without resorting to the Economy Act of 1932. Memoranda of agreement with Federal and state agencies for work on this comprehensive project plan need not refer to that Act as is customary in case of memoranda of understanding outside the Missouri River Basin.

FEDERAL INTER-AGENCY RIVER BASIN COMMITTEE

.3 Formal cooperation between the Bureau of Reclamation and other agencies has developed gradually from the early work with the Department of Agriculture and later with the Corps of Engineers on irrigation and flood control. A tripartite agreement between the Departments of Army, Interior, and Agriculture to insure cooperation in the preparation of reports on multiple-purpose projects was signed August 8, 1939. This was superseded by the quadripartite agreement of December 29, 1943, to include the Federal Power Commission. This agreement provided for monthly meetings of the Federal Inter-Agency River Basin Committee to achieve more complete cooperation on water problems involved in multiple-purpose projects. The committee was enlarged in 1946 to include the Department of Commerce, primarily in order to coordinate interagency cooperation with the Weather Bureau and Coast and Geodetic Survey. Section 1 of the Flood Control Act of December 22, 1944, requires that the Secretary of the Interior consult and exchange information with and provide an opportunity for review of planning reports by the Department of the Army and affected states in the instances enumerated in that Act. The activities of the Federal Inter-Agency River Basin Committee are extended through the Missouri, ★Columbia, and Pacific Southwest areas by basin or technical committees★ and through working subcommittees on Hydrologic Data, Sedimentation, Costs and Benefits, etc. Bureau of Reclamation representatives participate actively on these subcommittees.

WATER & POWER DEVELOPMENT

.4 Within the Department, cooperation on water and power matters is achieved through the ★Office of the Assistant Secretary for Water and Power Development. This office not only coordinates the interests of the Water and Power area with those of the Mineral Resources and Public Land Management areas of the Department, but provides representation of the Department on the Federal Inter-Agency River Basin Committee.★

GEOLOGICAL SURVEY

.5 At one time the Bureau of Reclamation installed many stream-gaging stations in connection with its investigations and operations, and maintained them by employing hydrographers and observers during the period of investigation or routine operation. There has been a disposition in recent years to turn this work over to the Geological Survey by means of memoranda of understanding whereby the Bureau transfers funds to the Survey. In 1946 the two agencies signed a general memorandum of understanding to provide for simple transfer

GEOLOGICAL SURVEY (Cont.)

of funds. Under this arrangement the Geological Survey has agreed to install and operate gaging stations as requested by the Bureau of Reclamation. Specific requests amounting to less than $5,000 per year may be made by the Bureau's Regional Directors to the Survey's district engineers on a reimbursement basis. The Bureau makes a transfer of funds to the Survey upon receipt of a Form 1080 voucher, covering the actual expenditures. More extensive work, including established programs, must be arranged between the Commissioner and the Director of the Geological Survey. These are financed through an advance of funds to the Survey. An effort is being made to transfer all continuing gaging stations and other water resources observations serving general or administrative purposes to the Geological Survey for operation and maintenance with funds appropriated directly to the Survey. Gaging stations operated for specific projects, either during a brief investigation period or as a part of normal project operations, will probably continue to be supported by the Bureau of Reclamation. A large part of the investigation stations will be installed and operated by the Geological Survey with General Investigations funds transferred for that purpose. Project operating stations, especially those on canals, will continue to be operated by project operating personnel. A special arrangement has been made with the Geological Survey for the publication of collected sedimentation records in Water Supply Papers. Whenever streamflow and related data are collected by the Bureau, copies of the records should be furnished to the Geological Survey so that it will have a complete file of all available data. The records should be transmitted to the most convenient field office of the Survey with a letter stating that they are for filing in the repository of streamflow data. The records for this purpose may be in any convenient form, including microfilm. Copies should, of course, be retained by the proper office within the Region and a copy should be provided to the Hydrology Division, Branch of Project Planning. Among the types of data of interest to the Survey for its repository are gaging station records on streams or canal headings, current-meter measurements, miscellaneous flood discharges, lake or reservoir elevations or contents, daily gage heights when they may be converted to discharge, ground-water records, well logs, discharge of springs, chemical analyses of surface and ground waters, and data on water utilization.

WEATHER BUREAU

.6 Considerable cooperation with the Weather Bureau is necessary during many phases of the Bureau's water studies. Some of this work is on special studies for which that agency is compensated for the work involved, while in others it provides its services as a part of its normal duties. The Weather Bureau has always been willing to make available its records of precipitation, evaporation, temperature, and other hydrologic data. The Bureau should, of course, hold its requests for uncompensated time-consuming services to a minimum. The Weather Bureau has many records available in its files that have not been published. A detailed discussion of some of the available data is given in Volume IV, Chapter 6.2, Basic Hydrologic Data. The Weather Bureau also serves as a central repository for weather data collected by many agencies, as discussed in Paragraph 1.4.10.★★★

WEATHER BUREAU & CORPS OF ENGINEERS

.7 Early in 1946 a memorandum of understanding was signed by the Bureau of Reclamation and the Weather Bureau, Department of Commerce, under which the Bureau of Reclamation transfers funds to the Weather Bureau for the support of the Cooperative Studies Section (Reclamation). This section makes meteorological studies to determine maximum possible precipitation and snowmelt for assigned stream basins above specified dam sites for use in the determination of spillway design floods. The Weather Bureau thus contributes highly specialized training in meteorological analysis. The work done is essentially similar to that performed by the Hydrometeorological Section of the Weather Bureau under a similar agreement with the Corps of Engineers, Department of the Army. The two sections work in close cooperation with a full interchange of data through agreement with the Corps of Engineers. Assignments of basin studies are arranged through the Hydrology Division of the Branch of Project Planning in order to obtain an orderly flow of work of highest priority. Because of the limited size of the Cooperative Study Section (Reclamation) and its heavy

assignments of a final type, the Hydrology Division, Branch of Project Planning, maintains a small staff of hydrometeorologists for the purpose of making rough preliminary determinations of maximum possible precipitation and in general maintains coordination between meteorological and hydrological work.

.8 An essential prerequisite to the work of both Weather Bureau Sections engaged in hydrometeorological studies is the collection and analysis of storm data. This is handled through the hydrologic network of the Weather Bureau. Support for the work was originally obtained from the Corps of Engineers and the Department of Agriculture with most of the load borne by the former. In Fiscal Year 1947 the increasing cost of the work required additional aid and the Bureau of Reclamation made a contribution toward its support. As a result of this contribution the Weather Bureau agreed to add to the network certain recording rain gages requested by the Bureau of Reclamation during Fiscal Year 1947 and part of Fiscal Year 1948, and to operate certain other gages previously operated by the Bureau of Reclamation. Because of the large number of requests for installations,★ not only for possible hydrometeorological analysis, but also for use in connection with project planning, operation, maintenance, and reservoir regulation★ the Weather Bureau is no longer able to establish additional gages without reimbursement. Accordingly, a memorandum of understanding was completed in February 1948, between the Weather Bureau and the Bureau of Reclamation, whereby additional gages may be installed on a reimbursable basis. This memorandum covers meteorologic installations of all types. The procedures under which installations will be requested are as follows: ADDITIONAL GAGES

★Operating offices of the Bureau of Reclamation are urged to discuss freely with Weather Bureau professional personnel, if available, the technical aspects of any contemplated expansion.

Operating offices are required to submit their recommendations to their Regional Office. The Regional Director may request the assistance of the Hydrology Division, Branch of Project Planning, and of the Weather Bureau engineers in formulating programs or in making reviews and analyses of proposals. If the Regional Office concurs with the operating office's recommendations, the Regional Office will write, (with copies to Hydrology Division, Branch of Project Planning, Denver, Colorado, and to the Director, Branch of Project Planning, Washington, D. C., attention 724) to the proper Regional engineer of the Weather Bureau and request an estimate of costs, if any. The Weather Bureau Regional engineers represent the Weather Bureau Regional Directors who have supervision of the Reclamation Weather Bureau project within their respective Regions. Operating problems should therefore be taken up with the Weather Bureau Regional Office concerned.

Upon receipt of the cost estimate, the Regional Office will decide whether to recommend the proposed installations.

The Regional Office will transmit its recommendations, together with a statement of availability for transfer in advance of any funds which may be required, to the Hydrology Division, Branch of Project Planning, Denver, Colorado, for clearance. Copies of this correspondence will also be sent by the Regional Office to the Director, Branch of Project Planning, Washington, D. C., attention 724, in duplicate.

The Hydrology Division, Branch of Project Planning, will review the Regional Office's recommendations. If the Hydrology Division, Branch of Project Planning, is in accord with the proposals, the recommendation will be forwarded to the Director, Branch of Project Planning, attention 724, with recommendation for authorization to proceed with installation. If the Hydrology Division, Branch of Project Planning, does not concur with the Regional Office's initial recommendations, they will be reconsidered jointly

ADDITIONAL GAGES (Cont.)

between the two offices until a mutually satisfactory solution is reached. Copies of all correspondence pertaining to such discussions are to be supplied to the Director, Branch of Project Planning, attention 724.

Upon receipt of authorizations to proceed, the Branch of Project Planning, Washington, D. C., will arrange for activation of the stations by the Weather Bureau, and keep the Regional Office and the Hydrology Division, Branch of Project Planning, informed of developments.

In order to expedite installations, the Branch of Project Planning will be informed by the Weather Bureau which of its offices is to participate in the activation of the new installations. Immediately upon receipt of this information from the Commissioner's Office, the Regional Director will arrange to supply the designated Weather Bureau office with the name and address of the Bureau of Reclamation engineer who is to collaborate with Weather Bureau personnel in establishing the installation. The Hydrology Division, Branch of Project Planning, Denver, Colorado, and the Director, Branch of Project Planning, Washington, D. C., attention 724, will be informed of the designated representative by copies of the correspondence.★

EXCHANGE OF STORM STUDY DATA

.9 In the initial stages of the cooperation between the Corps of Engineers and the Weather Bureau a program was initiated to analyze all significant storms of record. A list was prepared and a part assigned to each district office of the Corps of Engineers. On the entry of the Bureau of Reclamation, arrangements were made for a full interchange of data and participation in the storm study analyses by the Bureau of Reclamation. Lists of storm assignments have been given the several Regional Offices of the Bureau of Reclamation. In case the Bureau requires data on a storm that has not yet been analyzed by the Corps, the studies are undertaken by Bureau forces and the district office of the Corps to which the storm was assigned is informed of the undertaking and later furnished the results of the studies.

REPOSITORIES FOR HYDROLOGIC DATA

.10 ★By agreement of the various agencies interested in hydrology, the Geological Survey and the Weather Bureau serve as repositories for basic hydrologic data. All data on streamflow and related matters will be filed with the Geological Survey and all meteorological data will be filed with the Weather Bureau. The success of these repositories depends upon the cooperation of all agencies collecting basic hydrologic data of all types. Such a centralized system of filing will be extremely valuable to all concerned as it will make the data readily available to all interested agencies and to the general public. Also, records so filed gain value by such filing, should they ever be required for legal purposes. Therefore, the Bureau of Reclamation should send copies of any such data to the appropriate office for filing. The data provided should be either the original field records in a form suitable for filing or a listing suitable for filing and for reproduction by common means such as blueprinting, etc. Microfilm records are acceptable. The Geological Survey and the Weather Bureau reserve the right to select for filing only such data as they consider to be of adequate general value. Therefore, it is recommended that the acceptability of the data be determined in advance of the actual transmittal of the records. For its own protection and use, the Bureau should retain copies of the records in the proper office within the Region and in the basic data files of the Hydrology Division, Branch of Project Planning. The Geological Survey is interested in records such as gaging station records on streams or canal headings, current-meter measurements, miscellaneous flood discharges, lake or reservoir elevations and contents, daily gage heights when they may be converted to discharge, ground-water records, well logs, discharge of springs, chemical analyses of surface and ground waters, and data on water utilization. The Weather Bureau is interested in all meteorological data including precipitation, temperatures, humidities, wind movement, evaporation, etc. The records should be sent to the most convenient field office of the Geological Survey and to the appropriate Regional Hydroclimatic Center of the Weather Bureau. The addresses are given in Appendix I of Chapter 6.2 of this Volume of the Manual.★

SOIL CONSERVATION SERVICE

.11 A memorandum of understanding was signed April 15, 1947, between the Bureau of Reclamation and the Soil Conservation Service, Department of Agriculture, under which funds will be contributed by the Bureau and services will be rendered by the SCS in the collection and publication of snow-survey data and stream forecasts in the Western States, except the Sacramento-San Joaquin Basin of California where cooperation is with the California Department of Public Works, Division of Water Resources. Under the agreement the SCS coordinates the snow-survey activities of the Forest Service, several states, numerous irrigation districts, private power companies, etc. The Hydrology Branch, Project Planning Division, performs the necessary liaison between the Regional Office and the Soil Conservation Service. Recommendations for expansion of the snow-survey network may be made at any time, but specific requests for new snow courses should be submitted to the Hydrology Branch, by June 1 of each year. Under the memorandum of understanding the Hydrology Branch will inform the Division of Irrigation of the Soil Conservation Service, of the requests for new snow courses by July 15 of each year. The Hydrology Branch, and the Division of Irrigation will, together, prepare estimates of the reimbursable costs chargeable to the Bureau of Reclamation or funds to be advanced by the Bureau to accomplish the work. Where a snow course is beneficial to two or more Regions, the costs should be apportioned between them by agreements between the Regional Directors. By October 1 of each year, the Hydrology Branch will formally request the Division of Irrigation to secure the desired snow data for the courses finally selected. A list of offices desiring to receive the data will need to be provided at that time, to insure prompt dissemination of the information.

FOREST SERVICE

.12 A memorandum of understanding was executed between the Bureau of Reclamation and the Forest Service, Department of Agriculture, in Fiscal Year 1947 for a cooperative Snow Laboratory in the Fraser Experimental Forest, Colorado. This laboratory will be primarily concerned with rates of snowmelt and runoff under field conditions. While this agreement does not extend to the Corps of Engineers and Weather Bureau, these agencies are jointly conducting similar snow laboratories in the Central Sierras near Soda Springs, California; in the Willamette Basin Snow Laboratory in Oregon; and in the Upper Columbia Basin near Marias Pass, Montana. The Processing and Analysis Unit, Cooperative Snow Investigations, at Oakland, California, is maintained by these two agencies, but the Bureau of Reclamation is at present participating in the work by maintaining one employee of the Hydrology Branch, Project Planning Division, in the Unit.

RESERVOIR OPERATION REGULATIONS FOR FLOOD CONTROL & NAVIGATION

.13 Section 7 of the Flood Control Act of 1944 (58 Stat. 887) provides that: "Hereafter, it shall be the duty of the Secretary of War to prescribe regulations for the use of storage allocated for flood control or navigation at all reservoirs constructed wholly or in part with Federal funds provided on the basis of such purposes, and the operation of any such project shall be in accordance with such regulations . . ." [(Note: Since passage of the Act of July 26, 1947 (61 Stat 500), the above duty rests with the Secretary of the Army.)] Where Bureau projects include navigation or flood control, the Corps of Engineers of the Department of the Army shall be consulted during the planning of the project. When flood control space is allocated in a Bureau reservoir, tentative flood control operating regulations should be developed jointly by the Bureau and the Corps of Engineers. It is generally advisable for the Regional Director to work out a mutually satisfactory plan with the appropriate District Engineer of the Corps of Engineers before forwarding the information to Washington for final action. ★The Orders and Regulations of the Corps of Engineers, regarding the "Regulations Under Section 7 of 1944 Flood Control Act." are shown in Illustration 1. Copies of the proposed reservoir operation regulations for flood control shall be furnished to the Chief, Hydrology Branch, attention 758, and to the Chief Engineer, attention 220, Denver, Colorado, at the time they are submitted to the Commissioner for approval. Requests for information or assistance in the preparation and field negotiation of proposed regulations should be sent to the Chief, Hydrology Branch, Project Planning Division, Denver.★ The following policies shall govern the preparation of regulations for reservoir operations at the Regional level:

RESERVOIR OPERATION REGULATIONS FOR FLOOD CONTROL & NAVIGATION (Cont.)

A. The regulations shall be adequate to provide, as far as possible, a method of operation which will assure the achievement of the purposes to be served by the several reservoir functions.

B. Where several agencies have reservoirs on the same stream, or otherwise situated so that coordination of operation is necessary to accomplish the most efficient uses for which the reservoirs are authorized, consideration should be given to including in the regulations, procedures for cooperation among the agencies that will accomplish basin-wide coordination of operation consistent with forecasts of water supply and needs for proper administration of water rights within the basin.

C. Where reservoir operations are related to the activities of other agencies of the Department of the Interior, the Regional Director shall provide opportunity for these agencies to participate in negotiations relative to the development of regulations under Section 7 of the Flood Control Act of 1944.

OTHER FEDERAL AGENCIES

.14 Several agreements have been made in the past with other Federal agencies on project and river basin work, not only to utilize the services of highly trained personnel or survey parties and hydrographers not needed full time by the other agency, but to avoid duplication of work. Thus local agreements may be reached on division of work, such as surveys, sediment sampling, stream gaging, etc. The program of basin-wide studies begun in Fiscal Year 1945 placed emphasis upon Departmental action and as a result agreements for cooperative work have been completed for numerous project and basin investigations with other Interior Department agencies. The National Park Service assumes responsibility for planning facilities and evaluating recreational benefits. The Fish and Wildlife Service analyzes the effect of Bureau developments on wildlife and evaluates benefits under the Act of August 14, 1946. The Bureau of Indian Affairs presents plans for irrigation developments or arranges with the Bureau of Reclamation to do so. The Bureau of Land Management cooperates on matters of special interest to it. The Bureau of Mines assists in evaluating mineral reserves, such as coal, in reservoir areas. The Bureau of Reclamation and the Bonneville Power Administration cooperate on power market and design problems. Cooperation is also necessary with other agencies, such as the Public Health Service on matters of safety of domestic water supplies or degree of stream pollution; the Federal Power Commission on power market studies and regulation of power companies; the State Department, through the International Boundary and Water Commission on the Mexican boundary; and International Joint Commission on the Canadian boundary on treaty matters affecting international division of water.

STATE & LOCAL AGENCIES

.15 Cooperative agreements have been made with several Western states on both individual projects and continuing state-wide programs whereby the states contribute to trust funds, subject to withdrawals by the Bureau of Reclamation under specified conditions which may or may not also provide for use of state facilities, equipment, supplies, or personnel. Agreements with states are commonly for project or basin investigations, but may be for special purposes, such as the agreement once made with the State of Colorado, through its Water Conservation Board, for cooperation on consumptive use investigations on the Uncompahgre Project and on the Bessemer Ditch area in the Arkansas River Basin. Similarly, agreements may be entered into with counties and cities within the legal limitations afforded them by state laws. The joint investigations by various Federal, state, and local agencies in Santa Barbara, California, is a good example of coordinated activity.

BUREAU ORIGINATION & CLEARANCE

.16 Cooperative studies should be undertaken whenever they are determined to be advantageous to the Bureau of Reclamation in point of efficiency, economy, or saving of time. Regional Directors have been delegated authority to negotiate and execute cooperative agreements under specified conditions. Cooperative agreements not within the authority delegated to the Regional Director, should be reviewed by appropriate divisions of the Commissioner's staff and approved by the Commissioner. Cooperative agreements originating at Regional level must in any event be approved by Regional Counsel before being executed or before being sent to Washington for approval.

REGULATIONS UNDER SECTION 7 OF 1944 FLOOD CONTROL ACT

CORPS OF ENGINEERS, DEPARTMENT OF THE ARMY

REGULATIONS UNDER SECTION 7 OF 1944 FLOOD CONTROL ACT

4244.01 a. General. Section 7 of the Flood Control Act approved 22 December 1944 (58 Stat. 890; 33 USC 709) reads as follows:

> "Hereafter, it shall be the duty of the Secretary of War to prescribe regulations for the use of storage allocated for flood control or navigation at all reservoirs constructed wholly or in part with Federal funds provided on the basis of such purpose, and the operation of any such project shall be in accordance with such regulations: Provided, that this section shall not apply to the Tennessee Valley Authority, except that in case of danger from floods on the Lower Ohio and the Mississippi Rivers the Tennessee Valley Authority is directed to regulate the release of water from the Tennessee River into the Ohio River in accordance with such instructions as may be issued by the War Department."

4244.02. General Procedure Under Act.

a. Regulations will be developed as rapidly as possible for projects covered by section 7 quoted above which have been completed and are being operated by other agencies. When feasible, regulations for projects authorized for construction by other agencies and subject to provisions of section 7 will be studied during planning stages by the District Engineer concerned. Such investigations may result in recommendation of desirable changes in storage capacity allocations or in the design of auxiliary facilities. In the case of Bureau of Reclamation projects, this opportunity is available during the preparation of estimates of flood control or navigation benefits for use of the Bureau in their project reports. In order for estimates of these benefits to be made, the storage allocations and a plan of operation must be clearly established by the Bureau (Senate Document No. 247, 78th Congress, 2nd Session, assigns some of this responsibility to the Corps of Engineers in the Missouri River Basin) to provide a basis for determination of the requested benefit estimates.

b. It is essential, in furnishing comments requested by the Bureau of Reclamation on its projects, that care be exercised that any evaluation of flood control or navigation benefits indicate clearly the plan of operation on which such evaluation is based. This might be done by wording the comment somewhat as follows:

> "The Corps of Engineers considers that average annual flood control benefits in the amount of $_____ can be realized if the project is operated in accordance with the following plan."

REGULATIONS UNDER SECTION 7 OF 1944 FLOOD CONTROL ACT (Continued)

c. Estimates of flood control or navigation benefits should include the full value obtainable from use of the storage allocated to flood control or navigation and for which rules and regulations under section 7 of the 1944 Flood Control Act are to be prescribed. The responsibility for making the storage allocation is that of the operating agency and may include any or all of the following types of allocations:

(1) Year round allocations - every year and all years.

(2) Seasonal allocations - every year on a fixed seasonal basis.

(3) Variable allocations to flood control - varying from year to year and based on precipitational indices, snow surveys, or other watershed conditions, but available for flood control any year as required.

d. For storage not allocated as above, the incidental benefit value of the storage will be discounted. This reduction will apply to storage that the Bureau of Reclamation will operate primarily for purposes other than flood control or navigation and not subject to rules or regulations under section 7. One basis for the discount would be the assumption that the benefit of any estimated margin of error of prediction would be taken on the side of irrigation; for example, if the project were being operated primarily for irrigation in contrast to the probability that the margin of error would be on the side of flood control if the project were being operated primarily for flood control.

e. Areas where allocations and operation under classification c(3) can be successful, without appreciable allocations under c(1) or c(2) above, are limited to regions with significant floods resulting only from seasonal snow melt runoff. In other sections, benefits for such allocations would be incidental in nature, and subject to considerable discount and possibly might be of not definite value. An intermediate type of area exists where the rain flood season is distinct from the snow melt season and appreciable benefits may be obtained from combined allocations under c(1) and/or c(2) with c(3) above.

f. If incidental flood control or navigation benefits are evaluable for utilization of storage space other than that allocated under section 7 and are used for justification of the project, it is the responsibility of the operating agency to utilize such storage in a manner which will provide the incidental flood control or navigation benefits comparable to those assumed in justifying the project. Regulations would not be issued under section 7 for such operations. Upon request by the operating agency, the Corps of Engineers will be ready to assist in devising plans of operation for the use of storage other than that allocated to flood control in the interest of providing maximum incidental benefits for flood control or navigation.

4244.03 a. Policy Governing Preparation of Regulations. The following considerations are presented for general reference in prescribing regulations under section 7:

REGULATIONS UNDER SECTION 7 OF 1944 FLOOD CONTROL ACT (Continued)

(1) The regulations will be adequate to provide, insofar as possible, a method of operation that will achieve the maximum flood control or navigation benefits for the storage for the storage space allocated for those purposes.

(2) The Secretary of the Army is responsible for prescribing regulations for use of flood control or navigation storage under the law. It is, therefore, necessary that any regulations established should designate the District Engineer, or some other official responsible to the Secretary of the Army, as the representative to issue such instructions as are required under the regulations. To the extent practicable, regulations will be prescribed in such a manner that responsibility for operation of the project remains with the operating agency and that references to a representative of the Secretary of the Army for decision on operating details are kept at a minimum.

(3) Where other reservoirs in the same river basin are so situated that coordination of operation is necessary to accomplish most efficiently the uses for which the reservoirs are authorized, consideration should be given to the needs of basin-wide coordination in the preparation of regulations under section 7.

(4) Authority for the construction, operation and maintenance by the Chief of Engineers of reservoir projects of the Corps of Engineers fully covers the management of these reservoirs and it is not necessary for the Secretary of the Army to prescribe regulations for such projects pursuant to section 7.

4244.04. Presentation of Proposed Regulations

a. After final approval by the Secretary of the Army, the regulations are published in the Federal Register, and in supplements to Title 33 of the Code of Federal Regulations. Instructions for preparation of regulations for publication in the Federal Register (see Federal Register, Vol. 13, No. 199, 12 October 1948) state that maps and diagrams should be eliminated from regulations, if possible. However, operation charts indicating variable seasonal storage reservation requirements, permissible releases, rule curves or other graphical regulatory data considered essential to the regulations should be published. In the event it is necessary to publish illustrations, original tracings, satisfactory for reduction to a size not exceeding 7 by 10 inches, will be submitted.

REGULATIONS UNDER SECTION 7 OF 1944 FLOOD CONTROL ACT (Continued)

b. The regulations should contain a statement as to the frequency and extent of exchange of basic data between the representative of the operating agency and the District Engineer or other designated regulative official.

c. Proposed regulations under section 7 presented to the Chief of Engineers for approval will be accompanied by a regulation manual for the project, similar in scope but in less detail than those required for Corps of Engineers projects. Particular attention should be given to supplying an adequate listing of pertinent data for the project including area and capacity curves, spillway and conduit discharge ratings, plan and cross-section of the dam and plan of outlet gates. Technical investigations and supporting data involved in development of the required regulations should be adequately reported.

d. Tentative agreements regarding the text of proposed regulations should be reached with the operating agency at field level as early as possible during planning or construction stages of individual projects, in accordance with the preceding statements of policy, and submitted to the Chief of Engineers through channels for approval. It is not anticipated, however, that final regulations will be submitted to the Secretary of the Army for approval prior to the time the projects are to be placed in operation. During negotiations the Chief of Engineers should be kept informed of any question of policy which may arise. In the event of failure to agree, after all means of reaching a mutually satisfactory agreement in the field have been exhausted, results of the negotiations, with recommendations, will be submitted to the Chief of Engineers.

Interior - Reclamation - Denver, Colo.

CHAP. 2.1 PRECIPITATION

BASIC SOURCE OF WATER

.1 The basic source of water is precipitation, but in most parts of the world its occurrence is irregular and, to date, practically uncontrollable. Fortunately, nature provides a great basic system of control and collection and man adds to these his own development. The usual sources of water for developed supplies are streams, lakes, springs, and ground-water aquifers. Where no dependable streams or ground-water supplies are available, catchment slabs are sometimes constructed to intercept precipitation for storage in tanks or cisterns to prevent seepage or evaporation losses. Under particularly adverse island conditions, it may be necessary to distill sea water to provide domestic water supplies. Most uses require a surplus over the amounts actually consumed. Seepage losses, wastes, and unconsumed waters are frequently available for re-use, with or without treatment to make them suitable. Irrigation return flows and sewage effluents are examples.

★★★

FORMS OF PRECIPITATION

.2 Precipitation occurs as rain, snow, sleet, hail, or their modifications. Dew is a form of condensation on objects near the ground, but it is generally negligible in amount so far as uses of water are concerned. Rain is immediately available and beneficial to vegetation. It cools the air; it washes accummulations of dust from plant surfaces; and it enters the soil and is drawn up through the roots by process of osmosis into the plant. Snow, on the other hand, is relatively ineffective until it melts, although it affords vegetation a protective insulating blanket against extreme cold during the dormant season. Hail is frequently more damaging to vegetation than beneficial as its impact breaks off leaves and beats down tender plant stems.

DISTRIBUTION

.3 The distribution of precipitation over the earth surface is extremely variable. Moisture-laden air from over the ocean surfaces may be conveyed great distances by the winds. Its moisture is precipitated through cooling as the air rises over mountains or masses of colder air, or is lifted and cooled by convection. Precipitation is commonly most abundant along the coast line and the windward slopes of mountainous areas or in regions where masses of tropical and arctic air are in frequent contact. Such land areas are notable by the lush growth of all plants, including forest trees. In areas of lesser moisture, as in the Great Plains, vegetation consists primarily of grass. In drier areas lying in the "rain shadow" on the mountains, vegetation is sparse, consisting of sagebrush or stunted desert plants.

MEASUREMENT

.4 Precipitation is commonly measured in rain gages. These are of two types: (1) nonrecording, and (2) recording. Special gages equipped with windshields to minimize the effect of variable air currents are frequently used to measure snowfall. Gages are of many forms, from the highly accurate recording machines used by the physicist to the coffee can which the farmer places on his fence post. Frequently, estimates of storm precipitation are based upon the "catch" of rainfall in exposed tanks, buckets, or cans.

STANDARD WEATHER BUREAU GAGE

.5 The standard Weather Bureau gage is the most commonly used gage. It is an 8-inch diameter cylinder with a receiving funnel discharging into an inner cylinder of ★2.53 inches in diameter★ so that the depth is magnified 10 times to increase the ease and accuracy of measurements. It measures a depth of 2.0 inches, but considering that the inner cylinder may overflow into the outer container, it has a range up to nearly 24 inches without servicing. Directions for installing gages and operating them are given in Weather Bureau "Instructions for Cooperative Observers" Circulars B and C--Instrument Division, Ninth Edition, (Revised 1941).

FOREST SERVICE GAGE

.6 The Forest Service has developed an inexpensive rain gage using a commercial brass tube 2.416 inches inside diameter for a measuring receptacle and a galvanized sheet-iron shell 7.64 inches in diameter to give an areal ratio of 1 to 10. It has a measuring capacity of .5 inch and an overflow capacity of 6 inches. It has been produced by Forest Service personnel at a cost of less than $2 each.

Comparative tests 1/ show it to check more closely to the standard Weather Bureau nonrecording gage than does the regular Weather Bureau tipping-bucket recording gage.

RECORDING GAGES

.7 There are several types of recording gages. The electrically operated tipping-bucket gage has been most generally used at the first-order Weather Bureau stations, but clock-operated weighing gages with capacities from 6 inches to 30 inches (usually 12 inches) are more frequently used in the hydroclimatic network. Equipped with windshields, these gages measure snow as well as rain for periods up to 8 days, or even longer, without attention. The record is made by a pen or pencil trace on a drum chart in a manner similar to the operation of a continuous water-level recorder. Gages of this type range in cost up to about $450 each.

TELEPHONE & RADIO GAGES

.8 Telephone- and radio-reporting rain- and water-level gages have been developed in recent years and offer new possibilities for isolated areas where no regular observer can be employed, especially in connection with flood-warning systems. The gage readings are reported by appropriate combinations of simple code or tonal signals. Telephone gages may report when the gage number is called, or may report continuously over a special wire. Radio gages may be arranged to transmit data at regular intervals of time or with regular increments of precipitation. For example, the gage might be adjusted to signal every 24 hours and, in addition, every hour when the rate of precipitation exceeds 0.2 inch per hour. Automatic equipment is available for receiving and recording radio signals from a network of transmitting stations. Power is generally supplied by storage or dry-cell batteries even where transmission lines are available in order to insure operation in the event of a power failure. The radio transmitters usually operate in conjunction with clock-operated, large-capacity recording gages and may operate for months without attention, in inaccessible places. Whenever practical, the telephone gage should be used rather than the radio gage, because the number of wave bands available for radio transmission is somewhat limited. Likewise, the cost of the equipment for this means of transmission is generally less expensive than that for radio transmission. However, in many locations it is not practical due to the expense of constructing the telephone line. Also it may not serve the purpose because of the danger of losing the line and interrupting service at a critical time.

REGULATIONS FOR USING RADIO FREQUENCIES

.9 The operation of radio transmitting gages is under the same controls, as to frequency, as other forms of radio transmission. Certain radio frequency bands have been allocated to the Federal Government, some of which are suitable for the transmission of hydrologic data. The Inter-Department Radio Advisory Committee assigns frequencies to the several Federal agencies and applications must be made to that committee for the privilege of operating equipment at a specified frequency. The Branch of Power Utilization makes all applications for the Bureau of Reclamation, but applications for hydrologic data stations, whether for streamflow or rainfall, should be made through the Hydrology Division, Branch of Project Planning, for coordination among the several Regional Offices. In order to achieve coordination with other Federal agencies transmitting hydrologic data, the Weather Bureau representative on the Hydrologic Subcommittee of the Federal Inter-Agency River Basin Committee has been designated as liaison officer to other Federal agencies represented on the Hydrologic Data Subcommittee. Applications by any agency are cleared with the other agencies by the Weather Bureau liaison officer and a memorandum of clearance is given which then accompanies the application to the Inter-Department Radio Advisory Committee. If conflicts develop, the Weather Bureau liaison officer will attempt to reach a solution agreeable to all agencies involved. Applications should give the following data:

1/ United States Missouri Weather Review, 1942-70:267-268--"Reliability of Forest Service Type Rain Gage" by D. L. Hayes.

REGULATIONS FOR USING RADIO FREQUENCIES (Cont.)

(1) Location (latitude and longitude)
(2) Requested frequency
(3) Call letters (if already assigned)
(4) Proposed power of transmitter
(5) Hydrologic data to be transmitted
(6) Operation schedule, i.e., on call, automatic for 15 minutes per hour, etc.
(7) Type of transmission, i.e., C.W. amplitude, C.W. tone modulated, amplitude modulated phone, frequency modulation, pulse
(8) Justification of installation
(9) Cooperating agencies, if any.

SUITABLE FREQUENCIES

.10 Frequencies from 169.425 to 171.925 megacycles have been assigned for hydrologic and meteorologic data. When use of this band is not practicable because of line-of-sight transmission limitations, use may be permitted of certain frequencies now used by the Geological Survey: 2.248, 2.296, 2.484, 2.516, 2.652, and 2.844 megacycles. The band 406 to 413 megacycles has been allotted to mixed use including hydrologic data. Certain other frequencies may also be available where there is no conflict with other users.

PRECIPITATION RECORDS

.11 Precipitation records have been maintained by individuals, commercial corporations, and Governmental agencies for many years. Some of the records of Europe extend back for as much as 3 centuries. In the United States, few records are older than 100 years, although there are many records of 50 years. The distribution of precipitation stations follows closely the distribution of population. There are many records in populous sections, few in isolated rural areas, and scarcely any in uninhabited deserts and mountains. The importance of a widely distributed network of precipitation stations is now being recognized and through the efforts of Federal agencies under the coordination of the Weather Bureau this distribution is being achieved. The Bureau of Reclamation should give careful consideration to the adequacy of the existing network of observation stations in areas of present or future interest to its work. Where the network is inadequate for storm warning and flood estimating, the Bureau should arrange for the necessary stations through cooperation with the Weather Bureau or, if necessary, by making its own installations.

WEATHER BUREAU RECORDS

.12 The Weather Bureau, through its trained personnel and cooperative observers, obtains precipitation records throughout the United States. Records from most of the stations comprising the climatic network are published at the several section centers as daily totals in monthly "Climatological Data." Beginnings and endings of rainfall are recorded at first-order Weather Bureau stations and frequently by cooperative observers. These records are filed at the appropriate section centers. In the West these sections coincide with state boundaries, but in the smaller Eastern States two or more states may be included in one section. Climatological data have been published at most Western section centers since about 1890. Daily records prior to that time, with few exceptions, have not been published, but are on file in the records of the Weather Bureau and its predecessor, the Signal Corps of the Army, in the National Archives. Monthly totals for the stations operated in these earlier years have been published from time to time in climatic summaries. Hourly amounts of precipitation are available for the first-order stations, consisting usually of one or two stations per section, in addition to the section center, but these records were not generally published prior to 1940. Since 1940, with the formation of the hydroclimatic network, there have been added a large number of recording gages. Hourly records during storm periods for these stations are published in the monthly "Hydrologic Bulletin," published at eight Regional Offices. ★ See Paragraph 1.4.10, for information on repositories for hydrologic data.★

OTHER AGENCY RECORDS

.13 Most Federal and state agencies collecting precipitation records furnish their records to the Weather Bureau for publication, but in some cases, where stations have been maintained for special purposes, unpublished records are maintained in agency files. The largest number of these are maintained by the Forest Service, usually for information during the summer season when fires are a constant threat to the forests. In many cases power companies and

irrigation districts maintain precipitation stations for use in connection with their operations. Many individuals maintain unofficial gages for their own information. Such unofficial gages are especially abundant in the Great Plains where cloudburst rains occur with considerable frequency. Such records maintained through personal interest are valuable additions to the Government network in recording storm rainfall as many of them meet the standards of accuracy required by the Weather Bureau.

ESTIMATES .14 The continuity of precipitation records is occasionally interrupted because of damage to the equipment or failure of the observers to make or record observation. It is frequently desirable to utilize these broken records, necessitating estimates for the missing periods. Estimates are commonly made by correlations between nearby station records where storms are general in occurrence. Estimates of monthly precipitation, in areas subject to widespread storms, based on one or more records are usually quite dependable even though there may be some variation in point rainfall in individual storms. Where precipitation occurs in "spotty" storms, estimates of daily precipitation may be extremely poor and monthly totals but little better.

MEAN PRECIPITATION .15 In applying precipitation data to studies involving drainage basins or large project areas, it is frequently possible to utilize records from several stations. In these cases it is necessary to adopt mean values applicable to the area or to subdivisions of the area. If the records show little variation in the amount of precipitation recorded at the several stations, a simple average of the records is usually adequate. Where precipitation is normally greater over one part of the area than another because of differences in elevation or exposure, it is desirable to obtain a weighted average. If slopes and exposures are uniform the Thiessen method may be used. This method involves the subdivision of the area in such a way as to weight each precipitation station record by the area lying closest to it. Perpendicular bisectors are erected to lines drawn between precipitation stations on a map of the area. These bisectors form the boundaries of the areas to be used for weighting purposes. If slopes are variable and the Thiessen method does not give a reliable representation, it may be necessary to estimate isohyetal patterns which, on the basis of the prevailing conditions, reflect the range in elevations and exposures.

DISPOSITION OF PRECIPITATION .16 As rain falls on a soil surface, a portion filters into the soil, depending upon the infiltration capacity, and the remainder flows over the surface until it is absorbed or until it reaches a stream channel. That part of the water which is absorbed by the soil in excess of the moisture-holding capacity of the soil becomes ground water. As snow melts the water released by melting follows the same pattern. Detailed discussions of the behavior of water under these conditions are given elsewhere in this Volume.

PERCOLATION .17 Deep percolation is discussed in Chapter 2.3, in connection with ground-water supplies. Chapter 4.1 discusses the effectiveness of precipitation in supplying the moisture requirements for crops. Chapter 6.5 is concerned with rates of infiltration and the production of flood runoff.

CHAP. 2.2 SURFACE SUPPLIES

INTRODUCTION

.1 This chapter deals specifically with the location of surface water supplies. It discusses their measurement, the availability of records, and the estimates which must be made to supplement those records where they are not directly usable in the studies underlying the plans for the development and utilization of surface waters.

Surface water may include diffused water on the land surface but is here considered primarily as water flowing continuously or intermittently in surface channels from definite sources of supply, and waters flowing through lakes, ponds, and marshes which are integral parts of a stream system. When water is stored in lakes or reservoirs, its movement is merely retarded or halted temporarily for future release. Surface and ground water are closely related in that surface water, through percolation may become ground water, and ground water, through seeps and springs, or wells may become surface water. Both are subject to evaporation and to chemical and physical combination as a use depletion. Water supply studies affecting surface sources are predicated upon a continuation of the hydrologic cycle; however, the quantity available may vary from time to time. The analyses described are for the purposes of evaluating those supplies in order that they may be regulated and utilized.

STREAMFLOW RECORDS

.2 Records of daily discharge of streams are available for only a relatively short period of time. Few stations were established in the West before 1890 and the number was not significant until about 1912. It was not until after 1934, a year of widespread and serious drought, that public attention was directed to the vital importance of streamflow data. In early years private power and irrigation interests installed and maintained a few stream-gaging stations. Public interest was sporadic, however, and while programs were started by public-spirited state and Federal administrations, many of these stations were discontinued due to subsequent lack of interest. Station locations were frequently changed, depending upon the availability of observers or other considerations. Since 1935, cooperative agreements between the states, various Federal agencies, and the Geological Survey have increased in the number of adequately operated and maintained stations for which published records are available.

ACCURACY

.3 Through the years the accuracy of records has also improved. Many early records consist only of daily gage heights observed once or twice daily with few supporting current-meter measurements. Many of the gage-height records obtained by the Weather Bureau were used only to establish elevations and no discharge measurements were made until a gaging station was operated at the same location by another agency. ★If Weather Bureau gage-height records are used, care should be taken to determine if any changes have been made in the location and/or datum of the gage, and that the stage-discharge relation is fairly constant (see W.S. paper 771, pp. 196, 214, and 280-287).★ At present, an effort is usually made to install automatic water-level recorders even at temporary stations and to make current-meter measurements at frequent intervals considering the permanence of the stream channel control. In case of a few important stations involving shifting stream beds, the discharge is measured by meter every day, or oftener during flood periods. The accuracy of the records must be considered in water supply studies, and more conservative allowances made for the less accurate records. The old records are valuable, even though relatively inaccurate, as they may be the only measure of experience during early periods of drought or flood.

PUBLISHED RECORDS

.4 The Surface Water Supply Papers of the Geological Survey are the principal source of daily discharge records and practically all records of significance are published therein at present. For earlier years, however, a careful search should be made of other sources of data. Station descriptions as published in the Water Supply Papers frequently refer to such earlier records which were maintained for these stations by the Bureau of Reclamation, Corps of Engineers, or the several State Engineers. The Geological Survey has published special papers on many stream basins in which all significant records are compiled in monthly summaries. The Survey also issues from time to time Regional summaries listing all stations ever operated by the Survey and the periods of record available. Records of stations maintained by the International Boundary and Water Commission are published in a special annual bulletin.

State records are commonly published in the annual or biennial reports of the State Engineer, or in special reports of Water Conservation Boards, Reclamation Commissions, etc. Compilations of monthly runoff are frequently available in special reports of such agencies. Basin and project investigations of the Bureau of Reclamation commonly include compilations of records and these may be obtained by reference to report appendices or supporting data files.

UNPUBLISHED RECORDS

.5 Unpublished records of stations maintained by the Bureau of Reclamation have been compiled by the Hydrology Division with the exception of some canal stations which can be secured from the Project Offices. Unpublished records of the Corps of Engineers can usually be obtained from the respective District Engineers. Unpublished records of canal diversions may usually be obtained from State Engineers or their Division Engineers and Water Masters. Records of stations maintained by cities, irrigation districts, power companies, and industrial concerns are sometimes available. Records from these sources frequently represent confidential information and can be secured only through proper assurance that they will not be published or made available to competing or unfriendly interests.

RUNOFF ESTIMATES

.6 The present policy of the Bureau of Reclamation is to make basin surveys to determine the potential developments. The water supply studies for such basin reports are necessarily preliminary, confined to the use of available records and rough estimates based thereon. The basin reports set the pattern for planning and so permit the installation of gaging stations at or near the locations needed in more detailed investigations for future project planning reports. Unfortunately, sometimes it may be necessary to undertake occasional project investigations which involve utilization of streams without runoff records, with only brief or broken records, or with records at locations considerably removed from dam sites or other control points because desired stations have not been installed or, if installed, have not been continued in operation. Many points where data are desired have been relatively inaccessible or physically unsuitable for stream gaging. It is necessary in such cases either to delay the investigations until runoff records of a representative period are accumulated, or to estimate the runoff in lieu of records. Estimates can never fully substitute for records, but, depending upon their relative reliability and the accuracy demanded by the study, they may be acceptable. Even though sufficient records are available to establish what is believed to be a reliable indication of normal flow conditions, they may not cover years of critically low flow. Estimates to extend the records through critical periods are especially valuable. Many project failures can be traced to an inadequate consideration of experienced drought years.

Estimates are made for various periods, depending upon the requirements of study. In some cases daily discharges are needed; in others monthly or annual amounts will suffice. Water-level recorders sometimes fail to operate properly because of many factors such as silt or ice, in the inlet pipes and stilling wells; physical violence to the recorders, or clock failures; or the stage-discharge relation may change rapidly because of shifting control or scour. In the event of such failure, it is necessary to replace the doubtful record by estimates for the period. These estimates are usually made by the publishing agency but might be subject to critical investigation if warranted by a knowledge of actual conditions. Monthly runoff estimates are most frequently required, but where flood flows or direct diversion of streams fluctuating frequently above diversion canal capacity are involved, it is necessary to estimate daily discharges. Estimates may extend over entire years or only the seasonal periods when the station is not operated. Winter operation of recorders is frequently difficult and stations primarily for purposes of administering irrigation diversions are commonly discontinued during winter months. It is usually desirable to obtain as long a period of record, actual or estimated, as possible, but a period of several years covering a critical drought period with some years of normal and above-normal flow will usually be adequate for project water supply studies.

ESTIMATING METHODS

.7 There are many methods of estimating runoff. The accuracy of the various methods depends upon the ability and experienced judgment of the estimator to find and apply correlating factors which will produce a realistic synthetic

record, but, more than upon method, accuracy of estimate is dependent upon the accuracy and uniformity of available records. Wide dispersion from the mean relation between records is not conducive to reliability of estimates.

SELECTION OF STATIONS & METHODS

.8 Good practice requires the use of the nearest or most representative station records as a correlating factor first, extending operations to more distant stations as necessary. It is frequently possible to obtain better estimates by referring to two stations than to one, comparing with results obtained with stations above and below, or averaging estimates by two or more methods. Sometimes it is possible to approximate runoff at one station by combining records or using the difference between two records. Where there are appreciable differences in drainage or elevation above the point of study and above upstream or downstream stations, it may be possible to obtain more reliable estimates by reference to adjacent streams where conditions are more nearly similar.

CONSIDERATIONS

.9 In selecting stations for correlation, recognition must be given to exposure to storm movement and to the sun, and to depth and character of the soil and its vegetative cover. Care must be exercised to afford adequate consideration to corrections for storage regulation, to upstream diversions and return flow, and to stream bed losses. If time of travel produces lag, the records may be synchronized by advancing or retarding the dates used for comparison. General methods based on the relation of runoff to weighted average elevation, to precipitation, or to precipitation less infiltration or consumptive use, are generally too undependable for monthly estimates and should be employed only in estimating long-time averages, or for reconnaissance purposes. Runoff estimates based on individual storm analyses range in accuracy from "good" to mountainous areas to "unusable" on the plains where rainfall intensities and infiltration rates vary widely with time and location, and ground-water storage capacity is large. If estimates, on considered judgment, are too unreliable to be used, it will be necessary to install gaging stations and postpone project water supply studies until a representative record is obtained.

COMPOUND ESTIMATES

.10 Generally speaking, estimates should not be used as the basis for further estimates. It is better to change the method and make a single estimate.

GAGE-HEIGHT RECORDS

.11 Prior to 1912 a large number of the streamflow records published in Geological Survey Water Supply Papers appear as daily gage heights. Current-meter measurements are listed separately. If later Water Supply Papers do not give published reductions to discharge or monthly runoff, it then becomes necessary to prepare rating curves and estimate discharges as a first step in the study. This process is frequently disappointing because of the few measurements, unsupported curves at high discharge, and frequency of missing gage heights during flood periods. The gage-height records in many cases represent once-daily observations and may lack much of the accuracy of mean gage heights based on automatic water-level recorder charts. At some points it is possible to use the published "Daily River Gage Heights" of the Weather Bureau. These records include no current-meter measurements so they can be converted to discharges only when concurrent records at the same or nearby gage of the Geological Survey or other agency are available at some time during the period of record and there is clear evidence that channel control or datum has not changed. The records are not particularly good even under stable channel conditions because they are once-daily observations and do not reflect diurnal fluctuations in discharge.

COMBINATION OF RECORDS

12. The simplest and most accurate method of estimating the runoff at a given point is to add algebraically the various component parts. Frequently gages are maintained on two forks of a stream, or on one fork and on the main stream below the forks and it is only necessary to add them or deduct appropriate ones from a larger total. In other cases components representing only a part of the required runoff may be combined and the remainder estimated. Storage corrections may be made if records of reservoir capacity are available, allowing for evaporation, seepage, and bank storage if the accuracy of the data and detail of the study warrant it.

CORRELATION .13 If a gaging station has ever been maintained at the point of study, it may be possible to extend the record or to fill in periods of missing record by correlation with the concurrent records at other gaging stations. The relationship so established is then used as a basis for estimating the runoff for the point of study during the period when the record of the other station is alone available. Theoretically, only virgin flow records should be used for this purpose, but practically usable relationships can be established where consumptive uses vary but little from year to year and are approximately the same proportion of the runoff at the two stations. Storage regulations may be quite important and, if so, corrections based on recorded changes in storage should be applied before using affected records in correlations or the record should be discarded for correlation purposes.

Commonly the discharge, or runoff at one station is related to that at the other station as a percentage, but as the relationship may not be exactly proportional, or may vary with the stage, it is more appropriate to plot the discharge, or runoff, at one station against that at the other on arithmetic coordinate paper at suitable scales. It is usually sufficient to draw an approximate relation curve through the plotted points by inspection, disregarding widely divergent points, but some increase in accuracy may be obtained by using least square methods where individual points are known to be of comparable reliability. Frequently, points are not of the same reliability and it is necessary to use engineering judgment in considering their relative importance in establishing relationships. Single relation curves may be found to apply throughout the year for some stations, but for others it is frequently necessary to establish separate relationships for spring, summer, and fall periods, or even go to monthly curves. As the results are, at best, only estimates, they should be rounded appropriately. ★In plotting points for correlation curves, an examination of the precipitation records will often disclose the reasons for "erratic" points, and may also indicate that certain points should be disregarded in drawing the curve.★

Correlations can be established by reference to a single station, if the records are of similar magnitude, but where there are stations both above and below the point of study on the same stream, use of both records is frequently advantageous. Where it is necessary to correlate the runoff with that of stations on other streams, two or more relationships should be established, if possible, and both given appropriate consideration in selecting the estimates to be used. Frequently more realistic correlations are obtained in the case of tributary streams if the correlation is obtained by using the gain in runoff between two stations on the main stream, above and below the tributary, than by using the total runoff at either station. In the case of estimating main stream station runoff it is possible to correlate component records in various combinations. ★The upper end of a correlation curve often is extended as a straight line. Care should be taken to see that the slope of this line is in accord with the physical conditions affecting the flows at the correlation stations. Neglect of this may result in showing greater flows in a tributary than in the main stream.★ A good estimator must exercise imagination, ingenuity, and judgment, as well as technique.

PROPORTION .14 If no discharge records are available concurrently with records at comparable stations, it will be necessary to use other methods. Good results are usually possible by applying the ratio of drainage areas, especially if records are available on the same stream above and below the study point so that estimates can be obtained by interpolation. Consideration must, of course, be given to the occurrence of mountain and plains topography and of relative elevations of mountain areas. The percentage relations indicated by proportional areas should be modified in this case by a consideration of records of similar streams, or if no similar records are readily available, by judgment. Modifying coefficients based on mean elevations may sometimes be developed for these estimates. Where stations are available upstream and downstream from a point being estimated, an excellent approach can be made through a character-of-year analysis. A long-time average is obtained for new records at both stations and the percent of average computed for both. If in the given year the station upstream is 150

percent of normal and the downstream station is 160 percent of normal, it might be assumed the point in question would be 155 percent of normal. A remarkable consistency is usually found in deviations, and often, errors are indicated in individual years at one or more stations if they depart from the trend. A tendency for stations nearest the source of runoff or mountain stations to fluctuate less than plains stations is frequently noted. Often such an approach can be expanded to encompass an entire basin and will show an easily analyzed consistency for streamflow throughout an area.

RAINFALL-RUNOFF CORRELATION

.15 During the rainy season in the North Pacific coastal strip, particularly in mountainous areas, fair correlations may be obtained between rainfall and runoff. On the great plains, rainfall distribution is generally so erratic and soil conditions are so variable that correlation is almost nonexistent. In this method, monthly runoff is estimated directly from the weighted average rainfall recorded at precipitation stations in the drainage areas. Best results are usually possible when the runoff is segregated between base flow and flood flow. Base flows can be estimated from average flows of nearby measured streams, when no rain falls, in proportion to the contributing drainage areas. Where there is little difference in elevation or exposure the arithmetic average of precipitation records is sufficient, but it is usually preferable to weight the individual station rainfall by the area nearest that station using the Thiessen polygon method described in Chapter 2.1, or an isohyetal method. If there are large differences in elevation it may be desirable to weight the station record by the mean elevation of the area as well as by the area, as precipitation normally increases with elevation. Estimates of daily flow from rainfall are undependable because of the influence of such factors as intensity, ground-water storage, temperature, etc., which introduce lags in time and variability in losses, greatly affecting daily flows but becoming somewhat equalized over a period of a month. Monthly values are subject to seasonal variations in evaporation and transpiration losses, and for that reason, separate correlations should be developed for each month. The method is inferior to streamflow correlations and unusable in many areas. It should be used, if at all, with utmost caution.

PRECIPITATION LESS CONSUMPTIVE USE

.16 For rough estimates of average annual runoff, it may be possible to consider the runoff as a residual of precipitation after consumptive uses are supplied. This method can be used on small component parts of larger drainage areas for which runoff records are available, or on unmeasured streams adjacent to gaged streams. Annual consumptive use indices are estimated as the difference between precipitation and runoff depth using a straight or weighted average precipitation for the basin. By analyzing several measured drainage areas it is possible to develop consumptive use indices corresponding to various average elevations. Consumptive uses may also be estimated by the Lowry-Johnson method, described in Chapter 4.1, using temperatures measured at the nearest available temperature station and reduced or increased for difference in elevation by a conversion factor of 3.8° F per 1,000 feet, as a basis for determining effective heat. This method is of value for estimating average annual runoff of streams in mountainous or humid regions where precipitation and temperature data are available.

ALTITUDE RUNOFF

.17 An easier method, and a more reliable one for mountainous regions, is to correlate runoff directly with average elevation determined from topographic maps. This correlation includes at once the increase of precipitation and reduction of consumptive use with increase in altitude. Separate correlation curves should be developed for estimates of runoff on the windward and lee slopes of mountain ranges and for appreciable differences in latitude (zones should be limited to about 200 miles) as the distribution of precipitation and the temperature are affected by this factor, as well as by elevation. Rough estimates of annual and monthly ★runoff can be made by applying to the estimated average annual runoff the proper factors representing seasonal variations and monthly★ distribution of runoff as illustrated by measured streams of similar watershed characteristics. This method is especially useful in reconnaissance estimates of yield from watersheds to be intercepted by collection canals of transmountain diversion projects.

PRECIPITATION LESS INFILTRATION

.18 In plains areas where streams are normally dry or sustained by ground-water accretions in the form of a relatively uniform base flow, it is possible to make rough estimates by the methods customarily used in unit hydrograph analyses. This requires the determination of infiltration indices for various conditions of the watershed and an analysis of each significant rainstorm to obtain the mean intensities by convenient subdivision of time and area. The water not lost by infiltration reaches the stream as overland flow and the balance is absorbed by the soil to add to the base flow or consumed. This method is described in full detail in Part 6 of this Volume. Estimates obtained by this method are fairly reliable for heavy rainstorms of good coverage on well-saturated soils, but may depart widely from the truth for lighter rains with a "spotty" distribution and dry antecedent conditions. An accurate estimate of base flow is of course more important with the smaller floods. The method is not recommended for general use as it requires considerable detailed work, and a large number of precipitation stations. Usually, where sufficient precipitation stations are available, stream-gaging stations will also be available, and vice versa. Its limited accuracy reduces its use to reconnaissance. For detailed studies it is better to install the gaging stations needed, and wait until representative records are accumulated.

SNOW RUNOFF MELT

.19 During periods of rapid snowmelt it is possible to make fairly reliable estimates of runoff above base flow by correlating runoff to temperatures using either maximum or mean temperatures, above a base of 32° F. This method should be confined to relatively short breaks in records caused by failure of automatic recorders. The relation between temperature and runoff should be established from the records of the days immediately preceding and following the break. The relationship should further be checked by reference to adjacent streams for which records are available. It is thus an alternative to, or an independent check of, estimates based on a simple correlation of mean daily discharges.

NEED FOR ADDITIONAL GAGING STATIONS

.20 Although the Bureau of Reclamation at present relies to a considerable extent upon the Geological Survey for the measurement of streamflow, other than that connected with the operation of project distribution systems, responsibility remains with the Bureau for selecting many gaging station locations. One of the first steps in any project investigation is to ascertain what additional discharge records will be needed. In most cases it will be possible to arrange with the Geological Survey for the installation and operation of the needed stations, but if the Geological Survey cannot immediately undertake the work, the Bureau planning office should be prepared to start it. Likewise, it may be advantageous to establish temporary gaging stations to supplement those maintained by the Geological Survey in order to facilitate and improve hydrologic computations; frequently the Geological Survey is not interested in operating such short-time stations.

CHECK LIST OF STATION LOCATIONS

.21 Numerous factors must be considered in developing programs of surface water development. In many cases, gages have already been installed at, or reasonably close to, such locations. In others, stations have at one time been operated and should be re-established. In certain cases, the existence of another station nearby or the lack of suitable sites for station operation preclude installation. The scarcity of equipment or of funds justifiable for hydrologic study on the project may govern the decision whether or not to install gaging stations. Following is a check list of station locations:

A. Immediately below lakes or storage dams, including dam sites.

B. On lakes or reservoirs at or near dams.

C. On streams tributary to reservoirs immediately above flow lines.

D. Just above diversions to irrigated areas.

E. At points of minimum flow in irrigated areas.

CHECK LIST OF STATION LOCATIONS (Cont.)

F. At control points such as power plants, state and international boundaries, irrigation district boundaries, index points, etc.

G. Below irrigated areas.

H. Above cities or valleys subject to flood damage.

I. Above and below major springs in channels.

J. On canals above and below major tunnels where there is ground-water loss or accretion.

K. On tributary streams and drains near confluence with main streams.

L. Immediately below diversion dams.

M. At canal headworks or below wasteways.

N. At wasteway sluices or on wasteways just below sluices.

O. On major laterals at canal turnouts.

P. At strategic division points on canals or laterals.

Q. On individual turnouts if needed for administration purposes.

R. On all channels at valley cross sections under consumptive use study.

STAFF-GAGE OBSERVERS

.22 For work of a reconnaissance nature it will probably be sufficient to install staff gages and employ trustworthy local observers to record gage heights, daily or oftener, where the gages are not daily accessible to Bureau personnel. Farmers living near the gages may be induced to do the work. Housewives frequently perform excellent service as observers.

RECORDERS

.23 For more important work involving especially diurnal fluctuations in discharge, it will be desirable to install water-level recorders. If suitable equipment cannot be borrowed from the Geological Survey anticipating later transfer of the station to that agency, or from state agencies for temporary installations, it will be necessary to purchase it. Purchases are subject to Governmental regulations under schedules which vary in different parts of the Nation. The selection of equipment should be governed by the requirements of the case. For example, the Stevens L or E weekly chart recorders are cheaper than the Stevens A-35 continuous recorder yet fully as satisfactory, if the station is visited regularly or if qualified observers are available to change charts and wind clocks. Simple wells, inlets, and shelters may be improvised for temporary installations where the equipment will not be endangered by flood flows or vandals, but, generally, installations should follow Geological Survey specifications in order to insure satisfactory performance. Specifications for standard installations may be secured from any Geological Survey District office, or through the Chief, Hydrology Division of the Branch of Project Planning. Instructions and suggestions for selecting suitable sites and installing stations may be found in textbooks and in Geological Survey Water Supply Paper No. 888.

RELOCATION OF STATIONS

.24 Wherever it is necessary to change the location of a station, it is advisable to overlap the records of the old and new gages so that the user may compare the records to evaluate the possibilities of using the records at the two points together as record, or to provide a correlation between the two. While it is desirable that this overlap of records extend for about 2 years, one of only a few months will be helpful. When it is not practical to obtain a full record at each location, a series of spot discharge measurements should be made at each point, at various times. In this, it is advisable to make the upstream measurement first so that the discharge at each point will be most nearly the same. When the station is relocated only a short distance from its old point, with no

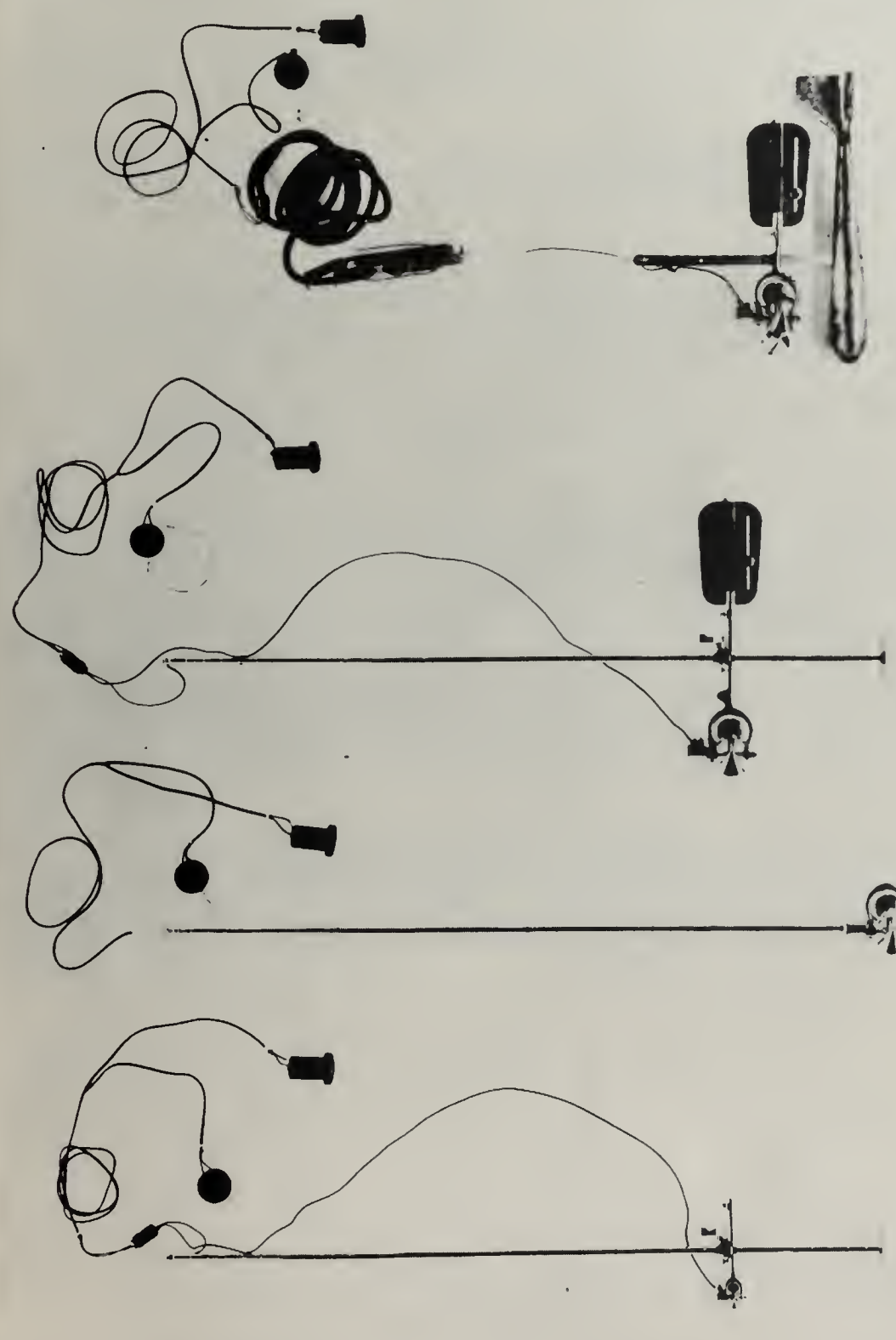
appreciable intervening drainage, the overlap of records may not be necessary. Any change of location should be fully noted so that the user of the records will be fully informed of the conditions.

HYDROGRAPHERS .25 Current-meter gagings can frequently be arranged with Geological Survey or state hydrographers, but in case such services cannot be secured, Bureau hydrographers should be employed or trained to do the work. Even though there may be no regular need for a hydrographer, it is recommended that someone in every planning office be able to make measurements and have on hand current-meter equipment, staff gages, etc., for emergency use. Such a man is useful in making up tail-water curves, checking canal seepage losses, making consumptive use determinations, etc., as well as in making flood-flow measurements when regular hydrographers are not available.

MEASUREMENT .26 This part of the Manual does not presume to discuss instructions in methods of making measurements of water. That subject is amply covered in Geological Survey Water Supply Paper No. 888, "Stream Gaging Procedure," and in the Bureau's special "Manual for Measurement of Irrigation Water." Copies of these should be secured for every field office. The cited references also discuss measuring equipment and its use for any purpose that is likely to be encountered under field conditions, or for most laboratory conditions. For unusual laboratory conditions it may be necessary to devise special equipment and techniques.

CURRENT METERS .27 While the Bureau has several types of current meters in operation, those shown on Illustration 1 represent the latest types except the Hoff meter, which is not popular. In fact, the Bureau has only two of the latter type. Of the various types, the one most generally used is the Small-Price meter, Type A. The BTA (Bob-tailed Type A) has been developed within the Hydraulic Laboratory of the Branch of Design and Construction, and combines the acceptable features of the Type A and the old acoustic model to produce a serviceable tailless instrument. All of the parts of the BTA meter are interchangeable with those of the Type A, except for the yoke and contact chamber which have been modified. The Bureau, in 1947, adopted as standard equipment the new Price-type current meter known as the "Pygmy" for the measurement of all streams which are so shallow that the larger Price, Type A meter will not perform with high accuracy. It is practicable to use the "Pygmy" meter for all wading measurements where the velocities do not exceed 3 or 4 fps. This new meter has a 2-inch diameter bucket wheel, a one-revolution contact, and no tailpiece or provision for cable suspension. As rapidly as practical, the Bureau intends to replace or modify its older types of current meters so that eventually all will conform to the standard group. This conversion will be accomplished by the Hydraulic Laboratory upon request from the appropriate field office. All old meters that are not serviceable will be dismantled and any usable parts salvaged. The details of the suspensions for all instruments except the BTA may be found in Geological Survey Water Supply Paper No. 888, "Stream Gaging Procedure." The BTA meter must necessarily be suspended on a specially constructed rod with an electrical conductor.

CARE OF CURRENT METER .28 All meters must be cleaned thoroughly and oiled after each day's usage or after a relatively long period of storage conducive to the collection of dust. It is, of course, not necessary to clean and oil the meter after each individual measurement when a series is made in 1 day. Whenever a meter is not in use, such as in transit or storage, the bucket wheel should be raised off the pivot by means of the knurled raising nut at the bottom of the shaft. Arrangements for the repair and procurement of current meters shall be made in accordance with instructions contained in Chapter 1.4 of Volume XIX.



STANDARD TYPES OF CURRENT METERS & SUSPENSIONS

H
R.

M

C
N

C
C

will be the responsibility of the using office. A copy of the purchase order to the Hurt Company should be sent to the Chief Engineer, Denver, Colorado, attention: code 290, to enable the accomplishment of inspection. The Hurt Company should also be furnished with bills of lading to forward meters to the Bureau of Standards and from that agency to the originating field office. Meters shipped for repair and rating must be carefully packed in their wooden carrying cases, to avoid damage in shipping. Any cases not fitted with clamps or blocks to prevent the meter from rattling around, should either be provided with a clamp or filled with wadded paper. (Not excelsior or similiar material.)

RATING OF CURRENT-METERS

.30 The frequency of the repair and rating of currentmeters is generally determined by the classification of the stream-gaging station at which they are used. Gaging stations are divided into two classifications as follows:

Class A--Those at which the discharge forms all or a component part of records likely to be published by the United States Geological Survey, State Engineers, or others; and other stations on streams, canal headgates, or other points of similar importance where the records obtained may at some future time be used in water supply studies, or for legal purposes.

Class B--Those of temporary value, such as canal measurements used in the distribution of water and unlikely to be referred to after the close of each current year.

Meters used in the operation of Class A stations must be rerated at least once each year while those used at Class B stations are to be rerated as often as considered necessary. Other items which control the frequency of repairs and rating include the presence of silt in the stream causing rapid wear of the intricate parts, chemicals which attack the instrument, damage as result of accident, etc. The rating will not be noticeably affected by minor adjustments to the tailpiece or replacement of a pivot so long as the bearing is in proper condition. Experience dictates that a bearing will function satisfactorily during the normal life of two pivots, hence one extra pivot is provided with each new meter. However, the rating of a meter will be seriously affected by damage to the bucket wheel, contact chamber, yoke, or wear of the intricate parts.

NEW METERS

.31 New meters and related equipment should be purchased directly from a manufacturer or supplier such as W. & L. E. Gurley, Troy, New York. Advertisements should conform with Bureau procurement requirements in Volume XIX. Serial numbers will be assigned to any newly acquired instruments in accordance with Bureau of Reclamation Manual Volume XX, Chapter 11.2.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

To: Chief Engineer

From:

Subject: Currentmeter shipped for repairs and rating.

1. The currentmeter described below is being shipped for repairs and rating.

Type _____ Meter Br _____

Meter to be rated (as received) (reconditioned)

Method of rating suspension desired _____

_____

Address to which meter is to be returned.

Official in charge _____ Title _____
Bureau of Reclamation

Address _____

_____

2. Remarks and suggestions for repairs:

_____

Enclose completed form in metercase.

CHAP. 2.3 GROUND-WATER SUPPLIES

INTRODUCTION

.1 This chapter deals with the occurrence, measurement, development, and control of ground water, and discusses the availability of ground-water records and reports, particularly as relating to ground-water supplies in contrast to ground-water drainage. The subject of drainage which is closely related to many ground-water problems, is discussed in Chapter 2.9 of Volume XVI and in Part 10 of Volume VII.

The Bureau of Reclamation may have occasion to utilize ground water for irrigation or for municipal, domestic, or industrial purposes. In addition, certain natural ground-water basins may be utilized to store and even to transmit and distribute surface waters; and drainage waters appearing as return flows may, if of suitable quality, be put to any of the usual Reclamation uses. The Bureau also encounters ground-water problems in and around dams, seepage ★from canals and laterals and★ from application of irrigation water, and in the construction of tunnels, canals, dams, and similar undertakings, but these are not appropriately discussed in this portion of the Manual, ★except as they are interrelated with supply studies in administrative and general considerations.★

Where ground water is plentiful at reasonable depths, a part or all of the total irrigation demand may be supplied from pumped or flowing wells. As ground water is a natural resource, which should be put to beneficial use, such withdrawals represent sound practice so long as they are not so large that the ground-water level is lowered beyond a depth from which the water can be economically withdrawn and applied to the land.

In many areas ground water may be present which can, if carefully used and conserved, add to the total developed wealth of the locality. The improvement during recent years of high-efficiency pumps has brought additional supplies of ground water within economic reach of irrigators where no other source of supply is available. However, in some areas where ground water has been pumped for many years, the supply has been depleted, or is fast approaching depletion, and in such areas artificial replenishment from surface supplies may be feasible.

FUNCTIONAL RESPONSIBILITIES

.2 ★The Branch of Project Planning is the Commissioner's staff office with primary responsibility for investigations of ground-water supplies. Technical supervision and assistance is provided through the Hydrology Division of the Branch in Denver, on planning and conducting investigations relating to water supply, and by the Branches of Design and Construction and Operation and Maintenance on matters within their respective areas of responsibility. Copies of any correspondence should be directed to the interested Branch or Division.

TYPES OF STUDIES

.3 The principal types of ground-water studies required by the Bureau of Reclamation are as follows:

A. Comprehensive ground-water studies for planning new or supplemental ground-water irrigation and municipal water supply projects on Regional, major basin, minor or subbasin, and project bases. Investigations consist of determinations of conditions in the areas for use in preparation of plans for the development and utilization of the water resources.

B. Studies of geological and ground-water conditions, including potential seepage, that may affect the stability, design, construction, and operating efficiency of proposed or existing dams, reservoirs, and canals, to determine the necessity for drainage, lining, grouting, or other corrective measures.

C. Studies to provide ground-water data required for design and construction of corrective drainage works on existing irrigation projects of the Bureau, and ground-water data relative to potential drainage problems on lands to be irrigated. See Part 10, Land Drainage, Volume VII.

D. Basic or historical ground-water studies as required in the case of damage claims due to adverse effects of Bureau operations on ground-water conditions or on the quality of water.

E. Research or improvement of methods relating to ground-water studies required by the Bureau.

This portion of the Manual deals primarily with the type of studies outlined in Subparagraph 2.3.3A. In many instances, however, these supply studies may be expanded or modified to provide most efficiently some of the additional data needed in the other types of ground-water studies.

COOPERATION WITH GEOLOGICAL SURVEY

.4 Cooperation with Geological Survey on collection of various types of Water Resources data is discussed in Paragraph 1.4.5 of this Volume, but is reviewed here in greater detail with reference to ground-water investigations. Problems relating to pollution of ground-water supplies may be studied in cooperation with the Public Health Service as discussed in Paragraph 4.1.21 of Volume VII.

A. Two general classes of ground-water data are required in connection with the work of the Bureau of Reclamation: (1) comprehensive physical data needed in planning and operation of water-use projects, and usually having some general public use and interest, and (2) specific, and usually local, data needed primarily for design and construction of Bureau structures, and having little or no general public use in addition to that of the Bureau. Records of the first type often are obtained under the Geological Survey program of cooperation with State authorities, with or without assistance of the Bureau of Reclamation. As a general rule, data of the second type are obtained by the Bureau of Reclamation personnel, with or without assistance from Geological Survey, as may be necessary or desirable in individual instances. Firm lines of responsibility are neither possible nor desirable, and in either case, ground-water investigations shall be conducted with the greatest possible coordination and cooperation between Geological Survey and the Bureau of Reclamation. There should be liberal and complete interchange of basic data at all levels upon either formal or informal request.

B. The Ground-water Branch of the Geological Survey maintains an experienced staff of ground-water specialists throughout the entire United States. Their services are available for studies relating to Reclamation activities, when requested, as required and appropriate, provided the results needed are such as will permit Survey, in making the study, to conform to its standards of performance for ground-water investigations. The type and degree of ground-water data requested from Geological Survey shall be consistent with the use that is to be made of the data by the Bureau of Reclamation. Work should not be requested that exceeds in degree or area the foreseeable needs of the Bureau of Reclamation. However, in planning ground-water studies to be conducted by the Survey for the Bureau, it must be fully recognized at all times that many of the Bureau's ground-water problems of a distinctive local nature depend for their solution upon knowledge of conditions which may be at some distance from the local problem itself. It will, therefore, frequently be necessary for Survey to make broad studies of a region, even to the extent of studying conditions in other neighboring surface basins, for the solution of such problems. When it is necessary to use Bureau funds for such purposes, the extent of the studies will be fully agreed upon between the field offices of the two agencies before the work is begun. The technical staff of Survey will confine such relative studies to those which in its experience have been shown to be essential, in whole or in part, for the solution of the particular Bureau problem under consideration.

C. Studies may be conducted by Survey either with its own funds as a part of its regular work or with funds transferred to the Survey by the Bureau of Reclamation for the specific purpose. In the latter case, such work, if

COOPERATION WITH GEOLOGICAL SURVEY (Cont.)

performed at Bureau request, should be conducted in accordance with an agreement negotiated by the Regional Director, with the review and approval of the Commissioner. The agreement should include, but need not be limited to, the following items:

(1) A statement setting out in detail the particular investigations or data required, comprising a definite program of designated scope.

(2) Requirements for progress or final reports should be explicit both as to content and as to when needed. Access to both the field work and office work by Bureau personnel should be provided for at any time regardless of the state of completion.

(3) Provision for reconsideration of the program at any time to permit modifications of scope or objective will usually be desirable.

In the event agreement cannot be reached to accomplish the items listed above in a manner satisfactory to the Regional Director, he shall refer the matter to the Division Director or Directors having cognizance, together with his recommendations for accomplishment of the work.

DEFINITIONS

.5 There has been much confusion in terms that denote water below the surface of the ground. An illustration prepared by Meinzer (Figure 2, page 23, Geological Survey Water-Supply Paper 494) shows the divisions of subsurface water which are adopted for use in this chapter. In the ensuing discussion of subsurface water, the following definitions of terms apply. In general, these definitions conform closely to the published works of Meinzer and others with the exception of "Safe Annual Yield" which is changed to "Economic Yield," and the "Physical Yield Limit" and "Annual Depletion Rate," which are added.

Subsurface water--the water that occurs beneath the surface of the land, also referred to as subterranean water and underground water.

Aquifer--a formation, group of formations, or part of a formation that is water bearing, with recoverable quantities of gravitational water.

Porosity--is the ratio of the volume of the interstices to the total volume of the rock or earth materials.

Permeability--the capacity of a rock or earth material to transmit water through its pores; also, the quantitative expression of this capacity. The permeability of a material is a constant dependent only on the nature of that material and not on the fluid. However, its units can be conveniently expressed in terms of a fluid having specified viscosity and density, such as water at a specified temperature.

The unit of permeability, called also the coefficient of permeability, may be expressed as a volume of flow of water per unit time per unit cross-sectional area per unit hydraulic gradient at a specified temperature. Thus the term "coefficient" as used in connection with permeability is dimensional in contradistinction with the usual use of the term as a dimensionless value.

Coefficient of transmissability--of an aquifer, which is also a dimensional "coefficient," as defined and used by the Geological Survey, is the product of the field coefficient of permeability (see Subparagraph 2.3.9A) multiplied by the thickness of the saturated portion of the aquifer. It represents the amount of water in gallons per day that would flow through a foot width of the saturated portion of the aquifer under a unit hydraulic gradient and prevailing water temperature.

The amount of ground-water flow through a section of an aquifer mav thus be determined either by computing the product of the field coefficient of permeability, the observed hydraulic gradient, and the area of the section through which the flow occurs; or by computing the product of the coefficient of transmissibility, the observed hydraulic gradient, and the width of the section.

DEFINITIONS (Cont.)

Zone of saturation--the zone in which the interstices of the rock or materials are filled with water under hydrostatic pressure. This zone contains the true ground water which is also referred to as phreatic water, and sometimes as underground water or subterranean water.

Zone of aeration--the zone of earth materials or rock in which the interstices are filled with air and water held or suspended by molecular forces, such as cohesion, adhesion, and surface tension. This water is referred to as vadose or suspended water. This zone may be divided into three parts: the soil belt, the intermediate belt, and the capillary fringe. This zone is sometimes temporarily filled by water in transit.

Ground water--the water in the zone of saturation.

G Water table--the upper surface of the zone of saturation where unconfined.

Artesian aquifer--an aquifer in which the water is confined by an overlying, relatively impermeable bed and is therefore under pressure sufficient to raise the water in wells above the top of the confined aquifer.

Piezometric surface--the imaginary pressure surface defined by the elevation to which water will rise in a well in a confined, or artesian aquifer (analogous to water table in an unconfined aquifer).

Isopiestic line--a line showing equal elevations on a piezometric surface.

Perched water--ground water supported by relatively impervious material above the prevailing water table of the region.

Capillary fringe--the belt immediately above the water table that contains water held up above the zone of saturation by capillary action.

Soil water--the suspended water in the uppermost belt of soil of the zone of aeration and lying near enough to the surface to be discharged into the atmosphere by the transpiration of plants or by evaporation from the soil. (Includes hygroscopic, capillary, and noncapillary water.)

Intermediate belt--the belt below the soil water and above the capillary fringe.

Field capacity--is the ★maximum amount of water that can be retained in a soil against★gravity.

Underflow--the movement of ground water down gradient in a permeable deposit which is more or less definitely limited at its bottom and sides by rocks of relatively low permeability.

Recharge--replenishment of the water supply in the zone of saturation. The term may refer to the processes of replenishment or the quantity of such water.

Intake area (of an aquifer)--the surface area where the water, from precipitation or surface flow, which eventually reaches the zone of saturation of an aquifer, is absorbed.

Catchment area (of an aquifer)--the surface area composed of the intake area of an aquifer and all other areas which contribute surface water to the intake area.

Specific yield--the ratio of (1) the volume of water which a rock or soil, after being saturated, will yield by gravity, to (2) the volume of rock or soil.

Coefficient of storage--the amount of water in cubic feet, discharged from each vertical column of the aquifer with a basal area of 1 square foot as the water level falls 1 foot. In an unconfined aquifer the coefficient of storage is essentially equal to the specific yield. In a confined aquifer it is equal to the cubic

DEFINITIONS (Cont.)

feet of water released from a column of the aquifer with a basal area of 1 square foot and with a height equal to the height of the aquifer when the artesian head is lowered 1 foot.

Specific retention--the ratio of (1) the volume of water which rock or earth materials will retain against gravity to (2) its own volume.

Specific capacity--the discharge of a well per unit of drawdown. It is usually stated in gallons per minute per foot of drawdown.

Economic yield--the maximum rate at which water can be artificially withdrawn from an aquifer throughout the foreseeable future without depleting the supply or altering the chemical character of the water to such an extent that withdrawal at this rate is no longer economically feasible. The economic yield varies with economic conditions and other factors such as recharge, natural discharge, pumping head, etc. The term may be applied with respect to the economic feasibility of withdrawal from the standpoint only of those who artificially withdraw water or from the standpoint of the economy of a river valley or other larger area to which the aquifer contributes water.

Physical yield limit--or potential yield--the greatest rate of artificial withdrawal from an aquifer which can be maintained throughout the foreseeable future without regard to cost of recovery. The physical yield limit is therefore equal to the present recharge, or that anticipated in the foreseeable future, less the unrecoverable natural discharge.

Annual depletion rate--the average rate over a period of years at which withdrawals deplete the storage in a ground-water reservoir.★★★

Drawdown--the lowering of the water table or piezometric surface caused by the discharge of ground water through wells, springs, or other openings.

Cone of depression--the depression produced in the water table or piezometric surface around a well that is discharging ground water.

★Overdevelopment--when the economic yield of an aquifer is exceeded, that aquifer is said to be overdeveloped. If the transmissibility of an aquifer is limited, excessive withdrawals in a restricted area may cause sufficient drawdown locally as to make it uneconomic to continue to withdraw water at that rate, even though the physical yield limit for the entire aquifer has not been reached. That condition is called local overdevelopment.★

Other terms--many terms used in ground-water reports are similar to corresponding terms relating to surface water and topography. The following is a partial list. All except "ground-water cascade" and "ground-water dam" are applicable to both water-table and artesian conditions.

Gradient	Divide
Contour	Ground-water cascade
Ground-water dam	Hydrostatic level
Pressure head	Stage
Profile	Fluctuation.

RECORDS & REPORTS

.6 Ground-water records are available covering many areas in the United States and many special reports have been published concerning the science of ground water. Most of these reports have been prepared by the Ground Water Branch of the Geological Survey, which cooperates with nearly all the states in this work. Many reports have been prepared by states, colleges, and universities, but very often as a state cooperative undertaking. Some private companies and individuals have written treatments of specific and general ground-water problems.

In 1905, a paper entitled "Bibliographic Review and index of papers relating to underground waters published by the United States Geological Survey, 1878-1904" was issued by the Geological Survey as Water-Supply Paper 120. In 1918, a more extensive compilation entitled "Bibliography and index of the

RECORDS & REPORTS (Cont.)

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publications of the United States Geological Survey relating to ground water" was issued as Geological Survey Water-Supply Paper 427, and in 1947 a publication listing 1,777 Water-Supply and other papers issued through January 1946, with a brief abstract or notation for each paper, was published as Geological Survey Water-Supply Paper 992. The latter paper should be consulted in any study of ground water. Many good papers have been presented in the Transactions of the American Geophysical Union. A few of the more outstanding general reports on ground water, to which reference often will be found desirable, are listed below.

Bennison, E. W.; Ground water, its development, uses and conservation; Edward E. Johnson, Inc., St. Paul, Minn., 1947.

Ferris, John G.; Ground water hydraulics as a geophysical aid: Michigan Department of Conservation, Geol. Survey Div., Technical Report No. 1, 1948.

Jacob, C. E.; On the flow of water in an elastic artesian aquifer, Trans. Amer. Geophysical Union, pp. 574-586, 1940.

Leggette, R. M., and others; Report of the Committee on Observation Wells, a preliminary manual of methods; United States Geological Survey mimeo. report, 1935.

Meinzer, O. E.; The occurrence of ground water in the United States, with a discussion of principles; United States Geological Survey Water-Supply Paper 489, 1923.

Meinzer, O. E.; Outline of ground-water hydrology, with definitions; United States Geological Survey Water-Supply Paper 494, 1923.

Meinzer, O. E.; Outline methods for estimating ground-water supplies; United States Geological Survey Water-Supply Paper 638-C, 1923.

Meinzer, O. E.; Plants as indicators of ground water; United States Geological Survey Water-Supply Paper 577, 1927.

Meinzer, O. E.; Ground water in the United States, a summary of ground-water conditions and resources, utilization of water from wells and springs, methods of scientific investigation, and literature relating to the subject; United States Geological Survey Water-Supply Paper 836-D, 1939.

Meinzer, O. E. (editor); Hydrology; Nat. Research Council, Physics of the Earth Series, Vol. IX, McGraw-Hill Book Co., 1942; reprinted, Dover Publications, Inc., 1949.

★Mitchelson, A. T. and Muckel, Dean C.; Spreading water for storage underground; United States Department of Agriculture Technical Bulletin 578, 1937.

Muckel, Dean C.; Water spreading for ground water replenishment; Agricultural Engineering, Vol. 29, pp. 74-76, 1948.★

Slichter, C. S.; Field measurements of the rate of movement of underground waters; United States Geological Survey Water-Supply Paper 140, 1905.

Theis, C. V.; The source of water derived from wells; Civil Engineering, pp. 277-280, May 1940.

Tolman, C. F.; Ground water; McGraw-Hill Book Co., 1937.

Wenzel, L. K.; Methods for determining permeability of water-bearing materials, with special reference to discharging well methods; United States Geological Survey Water-Supply Paper 887, 1942.

White, W. N.; A method of estimating ground-water supplies based on discharge by plants and evaporation from soil, results of investigations in Escalante Valley, Utah; United States Geological Survey Water-Supply Paper 659-A, 1932.

.7 Free water (water not combined chemically with other substances) exists throughout the upper strata of the earth. It originates from several sources, of which precipitation is the only one of practical importance. Water is retained in the upper belt of the zone of aeration by molecular forces. This water is important, as it supplies moisture for plant growth. The zone of aeration, particularly the soil belt, is important to the ground-water supplies, as it determines the rate of percolation from the surface. OCCURRENCE OF GROUND WATER

Some water exists in practically all the interstices of granular materials such as sand and gravel and in the cracks and crevices of hard rocks such as quartzite, igneous rock, and limestone. The best aquifers are those of unconsolidated granular materials such as sand and gravel, cavernous volcanic rocks, and formations of cavernous limestone in which the water flows through solution channels. Sandstones are generally rather poor aquifers in comparison to the others, except those having large crevices, those with enlarged openings where the cement has dissolved and loose sand has washed out, or those that are poorly cemented and with various degrees of consolidation but which have not yet reached the stage of metamorphosis of quartzite.

The value of a geologic formation as an aquifer is determined in a large part by its permeability and thickness. In granular deposits the degree of consolidation affects the permeability and hence has a bearing on the value as an aquifer. The size of the grains and uniformity are particularly important. For example, common clay is one of the most porous materials, yet because the grains are so extremely fine it is practically impervious.

The impermeability of shales and clays has an important effect on the movement of ground water in that they confine such movement to the more permeable strata such as sandstone and sand and gravel. A permeable stratum may be covered with a relatively impermeable clay or shale, in which case the water entering the aquifer will be confined by the overlying stratum. The water within the confined strata, and especially the water at lower elevations, exists under hydrostatic pressure so that if the confining stratum is penetrated by a well or other opening, the water rises to the elevation of its hydrostatic head. Such a well is referred to as artesian if the water reaches above the top of the saturated aquifer; if the water reaches the surface of the ground it is known as a flowing artesian well.

.8 Ground water is derived chiefly by the downward seepage of surface water, either directly from rain or melted snow or from streams and lakes supplied by rain or snow, or from irrigation. Of the total amount of precipitation or stream flow, only a part enters the ground; some is directly intercepted by vegetation and evaporated; some is evaporated as it runs over the surface; and some remains as surface water. Of the part that enters the ground, a portion becomes soil moisture and may be returned to the atmosphere through transpiration by plants or evaporation. A portion may be held by molecular attraction within the intermediate belt between the soil moisture belt and the capillary fringe and the rest finally reaches the zone of saturation and becomes ground water. Where the water table is near the surface, water may be discharged by evaporation and transpiration from the capillary fringe, or in extreme cases, directly from the ground water. Thus the amount of ground water available to a given area depends on a number of factors: the amount and distribution of precipitation and surface flow, the type of soil, the topography of the land, the extent of the intake area and catchment area, the amount and type of vegetative cover, the season of the year, the previous condition of saturation, the depth to the water table, and the permeability of the rocks. In artesian areas the available supply is dependent also upon the permeability and length of the aquifer from the intake area to the point of use. RECHARGE

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RECHARGE (Cont.)

Because ground water supplies are derived ultimately from precipitation, it may be necessary to make an estimate of the potential recharge from the precipitation on the catchment and intake areas. In a study for this purpose, consideration should be given to the amount of precipitation, its form (i.e., rain or snow) and distribution, records of runoff, consumptive use, and the retention rates as derived by methods outlined in Part 6 of this Volume. From a study of these factors, some estimate can be made of the potential recharge.

Artificial recharge of ground water has become an important adjunct in maintaining sufficient supplies of ground water in certain areas of heavy use. Recharge through wells has long been used to drain swamp lands and to dispose of sewage, oil-field brines, and other waste water. On Long Island, New York, the return of cooling water to the ground by means of recharge wells has helped considerably in stopping an alarming decline in water levels; and at Louisville, Kentucky, the introduction of treated cold surface water into the alluvium of the Ohio River during the winter months through existing wells has alleviated the summer shortage of water for industrial use in parts of the area. In many parts of the West, especially in California, water spreading--the diversion of surface water over areas favorable for percolation into the ground--has been practiced successfully.

MOVEMENT OF GROUND WATER .9 In general, each water particle in the zone of saturation is moving from some point in the intake area where it reached the zone of saturation to some point of discharge. The path it takes may be short and simple or long and complicated. It may be only a few feet or several hundred miles in length. The water may travel only a short distance below the surface or it may go thousands of feet below the surface. The natural rate of movement may vary considerably in the different aquifers, from many feet per day to a few feet per year.

The movement of ground water is caused by a difference in elevation between two points on the water table, or in the case of a confined aquifer on the piezometric surface. The flow of water through granular material is laminar or viscous, that is, the velocity varies directly as the difference in head between two points. This movement is expressed mathematically by Darcy's formula, which is as follows:

$$Q = KA \frac{dh}{ds}$$

in which Q equals the flow, A is the cross-sectional area, K equals the coefficient of permeability, and dh and ds are respectively the infinitesimals of difference of head, h, and slope distance, s. ★★★ The values on the right-hand side of this equation, except K, may be obtained by direct measurement; K, however, must be obtained by testing the material in which the water exists. The difference in head is distributed continuously, but not necessarily at a constant rate all the way from the intake to the exit of the water. A contour map of the water table or piezometric surface will show the direction of horizontal movement of ground water, the water flowing at right angles to the contours from a point of higher to one of lower head.

By contrast to laminar or viscous flow, in turbulent flow the velocity varies approximately as the square root of the difference in head. It is unlikely that there is any turbulent flow in underground water except in the cavernous passages in limestones, lavas, or gypsum formations and possibly through deposits of boulders, cobblestones, and coarse gravel. The applicability of Darcy's formula to flow through the fissures, joints, and crevices of igneous or similar rock may be open to question, but at present there is no other means of measuring the flow through such formations. However, except near discharging wells, and in rocks with very large openings in which water flows much as it does on the surface, Darcy's law probably applies for all practical purposes.

The units used for the coefficient of permeability determine the units of flow computed from Darcy's formula. It will be found convenient to use the following units:

MOVEMENT OF GROUND WATER (Cont.)

Q = flow in cubic feet per year

K = Bureau of Reclamation unit of permeability in cubic feet per square foot 1/ per year per unit gradient

A = Area in square feet

$\frac{dh}{ds}$ = slope of water table or hydraulic gradient in feet per foot.

A number of coefficients of permeability have been proposed by different investigators concerned with flow through porous media. Several of the more commonly used coefficients, that may confront employees of the Bureau of Reclamation, are accordingly defined herewith.

A. The Geological Survey coefficient of permeability for a material is expressed in Meinzer's units as the flow of water at 60° F, in gallons per day through a cross section of 1 square foot under a unit hydraulic gradient. For computations of flow through aquifers, a field coefficient of permeability is commonly used, expressed in the same units as above but applicable to the prevailing water temperature instead of the above stipulated water temperature of 60° F.

B. The Bureau of Reclamation unit of permeability is the volume of water, in cubic feet, passing through an area of 1 square foot of the material in 1 year under the action of a unit hydraulic gradient. The value so derived is based upon a standard temperature of 68° F, a factor generally not considered in field determinations.

C. The petroleum industry commonly utilizes a unit of permeability called the "darcy" which is defined as the volume of fluid in cubic centimeters per second passing 1 square centimeter under a pressure of 1 atmosphere per square centimeter and a viscosity of 1 centipoise.

★D. In most agricultural soils work, other permeability units are used (see Chapter 2.10, Volume V).★

In ordinary field tests, however, the factor for temperature (or for viscosity) is usually neglected or omitted from calculations because the temperature of the ground water in a specific locality is substantially uniform and hence the omission of that factor does not affect the result. If, on the other hand, field tests of permeability at different locations or tests in the laboratory are to be compared, that factor must be included.

The following tabulation shows the factors necessary to convert from one system of units to another when the temperature is 60° F:

FACTORS* FOR THE CONVERSION OF COEFFICIENTS OF PERMEABILITY FROM ONE UNIT TO ANOTHER

1	2	3	4
From To	Meinzer	Bureau**	Darcy
Meinzer	1	4.9×10	4.9×10^{-2}
Bureau**	2.0×10^{-2}	1	1.0×10^{-3}
Darcy	2.0×10	1.0×10^{3}	1

* Multiply value of unit indicated in the first column by factor shown in Columns 2, 3, or 4 to obtain corresponding values for the desired unit.

**As used by the Bureau of Reclamation.

1/ Refers to square feet at right angles to flow.

D. MOVEMENT OF GROUND WATER (Cont.)

Extensive investigations have been made to determine the limits of gradient under which Darcy's formula is applicable. Experiments conducted by the personnel of the Geological Survey some years ago have shown that water will flow in accordance with that formula under extremely small gradients, only a few inches per mile. It may therefore be generally accepted that Darcy's formula is applicable to most conditions under which the Bureau will deal with ground water. ★ However, field explorations and permeability tests have revealed bodies of clean, uniform-sized gravel or badly fractured rock in which Darcy's formula would not be applicable at the hydraulic gradients, which are or may be effective.★

As may be inferred from a knowledge of soil and rock materials, the coefficient of permeability varies over a wide range. Tests made in the Hydrologic Laboratory of the Geological Survey have found coefficients of permeability ranging from about 0.0002 to about 90,000 in Meinzer's units, a ratio of 1 to 450,000,000.

Chapter 10.3 of Volume VII, which discusses Land Drainage, also contains information on the coefficient of permeability.

FACTORS FOR THE CONVERSION OF COEFFICIENTS OF PERMEABILITY FOR VARIOUS TEMPERATURES

Water Temp. °F	Column* A	Column* B	Water Temp. °F	Column A	Column B	Water Temp. °F	Column A	Column B	Water Temp. °F	Column A	Column B
40	0.73	1.37	50	0.86	1.16	60	1.00	1.00	70	1.15	0.87
41	0.74	1.35	51	0.87	1.15	61	1.01	0.99	71	1.16	0.86
42	0.75	1.33	52	0.88	1.13	62	1.03	0.97	72	1.18	0.85
43	0.76	1.31	53	0.90	1.11	63	1.04	0.96	73	1.19	0.84
44	0.78	1.28	54	0.92	1.09	64	1.05	0.95	74	1.20	0.83
45	0.79	1.26	55	0.93	1.08	65	1.07	0.93	75	1.22	0.82
46	0.80	1.24	56	0.94	1.06	66	1.09	0.92	76	1.23	0.81
47	0.82	1.22	57	0.96	1.04	67	1.10	0.91	77	1.25	0.80
48	0.83	1.20	58	0.97	1.03	68	1.12	0.89	78	1.26	0.79
49	0.85	1.18	59	0.99	1.01	69	1.14	0.88	79	1.28	0.78

*To convert the coefficient at 60° F to any other temperature between 40° F and 80° F multiply by the factor in Column A opposite the temperature desired. To convert the coefficient from any temperature between 40° F and 80° F to 60° F multiply by factor in Column B opposite the water temperature.

DISCHARGING WELLS .10 The continual withdrawal of water from wells is made possible by the fact that pumping reduces the elevation of the water table or piezometric surface at the well, thereby setting up a hydraulic gradient toward the well from all directions, thus causing ground water to flow toward the well.

When a well in an unconfined aquifer is pumped the water table assumes a shape somewhat like an inverted cone centering about the pumped well. This is called the "cone of depression." The exact shape and size of the cone will depend on the slope of the initial water table, the permeability and specific yield of the aquifer, the rate of pumping, and the duration of discharge since

DISCHARGING WELLS (Cont.)

the start of pumping. During the early period of discharge most of the water will come from storage in the immediate vicinity of the well, by unwatering the material within the cone of depression. However, as pumping is continued a hydraulic gradient that is nearly an equilibrium gradient will be established near the well and water will be transmitted to the well at nearly the rate at which it is pumped. The cone of depression will continue to expand, draining water from farther and farther away, and the decline in the water table will continue, but at a diminishing rate.

If no water is added to the ground water, the water table will continue to decline. Recharge will reduce the rate of decline, or stop it altogether, by replenishing the supply.

In confined aquifers, the piezometric surface behaves similarly to the water table in the vicinity of a discharging well, except that instead of an actual decline in the water surface it is a decline in pressure. Water is first removed from storage by the compaction of the aquifer and associated beds and then by the movement of the water within the interstices of the material toward the well. The amount released by the compaction of the aquifer and the associated beds is much less than the amount released by unwatering an unconfined aquifer; consequently the development of the cone of depression is much more rapid and its extent is greater. As long as the well is pumped the cone of depression must continue to expand until it reaches the area of recharge or natural discharge. There a relatively small decline in the water level will induce additional recharge or decrease the natural discharge, so that equilibrium may be established.

DISCHARGE

.11 Natural discharge of ground water may occur through springs or seeps by gravity flow or by the less conspicuous but equally effective process of evaporation and transpiration. Generally a combination of these methods occurs, but in varying proportions. In humid areas effluent seepage is the predominant method in the winter months when plant life is dormant and lower air temperatures reduce the ability of the air to absorb moisture, but during the growing season effluent seepage may account for only a small portion of the total discharge of ground water. In arid regions, springs and streams are scarce and in many such areas evaporation and transpiration processes account for the major part of the ground-water discharge. Artificial discharge occurs through wells, improved springs, galleries, tunnels, dewatering operations, road cuts, etc. By far the greatest artificial discharge is from wells.

METHODS OF INVESTIGATION

.12 No two ground-water problems are exactly alike and no set method of investigation can be outlined. Conditions in the field, purposes of the investigation, and data required for the solution of the problems involved determine the methods to be used. However, certain basic data are necessary to the solution of practically all areal problems of ground water, and a number of general procedures have been developed for obtaining such data. It is the purpose of this portion to outline these general methods and indicate the data needed. The data necessary to a full understanding of a ground-water problem differ among various problems and with the solutions sought. In general, the basic data needed include the geologic composition and boundaries of the aquifer, the amount of recharge that aquifer receives and from what sources, the behavior of the water within the aquifer, the quality of the water, and the amount of discharge and the ways in which it occurs. These basic data may assume various forms, dependent upon the available facilities or on the methods of analysis to be adopted.

WATER ANALYSES

.13 The collection and analysis of water samples is important in any ground-water investigation. Its purpose is to determine the quality of the waters in an area and usually presupposes a knowledge of the geology of the area, in order to identify correctly the horizons from which the waters are derived. However, it is considered here first because, with a limited knowledge of the geology of the area, it is often possible to collect a small number of representative samples for analysis. These analyses may show the water to be unfit for the intended use, permitting abandonment of the investigation altogether, or limit the area or horizons from which water of suitable quality may be derived.

WATER ANALYSES (Cont.)

A comprehensive program of water sampling should be made some time during the investigation. Most of the samples can probably be obtained from existing wells but occasionally special effort must be made to get them. This may require special drilling of wells or driving of well points. The type of analysis will depend on local conditions.

Often a few "complete" analyses from wells in different parts of the area, supplemented by a greater number of less complete analyses, are sufficient to define the quality of water. The "complete" analyses should involve determinations of the principal positive and negative ions found in natural waters; calcium, magnesium, sodium, potassium, iron, boron, carbonate, bicarbonate, sulfate, chloride, nitrate, and fluoride, plus the hardness (calculated), specific conductance, pH, percent sodium, and total dissolved solids. The partial analyses may include only the predominate negative ions, such as bicarbonate, sulfate, and chloride, plus the hardness (soap) and specific conductance.

Special problems may require special analyses. For instance, a salt-water contamination problem may involve the determination of only specific conductance and chloride ion of samples from many wells to define the contaminated area, and repeat determinations at intervals from several key wells to define the movement of the salt water. In irrigation, the percentage of sodium ion and the total concentration of soluble salts are the important factors in determining the quality of the water, and for certain crops the amount of boron is important. The suitability of water for irrigation use depends not only upon the quality of the water, but also upon the character of the soil on which that water is to be applied.

One example of a special problem which may arise in connection with domestic supplies is the amount of fluoride in the water. There is strong presumptive evidence that excessive amounts of fluorine in drinking water may be a positive factor in dental fluorosis. Some other ions which may cause special problems are those of arsenic, lead, iron, selenium, hexavalent chromium, nitrogen as nitrates, and others. For industrial uses, a determination of silica (SO_2) should also be made in a complete analysis of a ground-water supply that may be used for boiler feed, cooling, etc. For some processing or chemical plants, it will be necessary to have information on other chemical components.

Temperature data may be obtained during the course of the well inventory and can usually be taken by inserting the bulb of an accurate pocket thermometer into the discharge of a well and reading temperature directly. Care must be taken that the reading represents the true temperature of the ground water and is not affected by other factors. The well should be pumped or allowed to flow until the water temperature becomes constant or long enough to remove all the water standing in the well. The temperature of the water is an important consideration in most industrial uses, especially cooling, but may also be a factor in the amount of induced filtration to wells from surface sources and in the rate of percolation during water-spreading operations. (Further details on Quality of Water will be found in Chapter 2.4.)

WELL INVENTORY .14 An inventory of existing wells and springs supplies much information which may be useful in many different phases of a ground-water investigation and should be one of the first procedures in the field. There is provided for use of all offices a Bureau of Reclamation Form 7-1426, Well Record, on which the history of the well and complete physical data regarding it should be recorded whenever a well inventory is undertaken. Although it is seldom possible to fill out Form 7-1426 completely, the use of it makes for uniformity in recording data, insures that the items will not be overlooked, and makes a permanent record of the well. The originals or copies should be made a part of the files of supporting data for the studies.

GEOLOGY .15 Rarely is the geology of an area known in sufficient detail beforehand to define accurately the boundaries and composition of an aquifer. More often the opposite is the case, and considerable geologic work is required. Practically every phase of geologic work has been utilized by ground-water geologists at

some time or another, including surface and subsurface mapping, mineralogy, paleontology, test drilling, seismic and resistivity studies, electric logging, and many specialized studies. Each area will have its particular problems and may require any or all of the special skills of a geologist.

OBSERVATION WELLS

.16 An observation-well program must often be set up during an investigation to determine the fluctuation of the water table or piezometric surface. An observation well is one in which measurements of the water level are made at regular intervals or on which a continuous recorder is installed. Most often, the observation well is an already existing used or unused well, but sometimes it is desirable to install special wells for observation purposes. The Ground Water Branch of the Geological Survey has issued a mimeographed manual on observation wells, giving methods of selecting the wells, protecting them, measuring them, and other factors. If an observation-well program is considered necessary, it should be set up early in the investigation, usually during or just after the well inventory, because the value of the records of water levels increases with the length of the record.

TEST DRILLING

.17 The value of test drilling in solving ground-water problems is becoming more widely recognized and often is the only way in which sufficient knowledge of the material underlying an area can be obtained. Test drilling is costly, so that great care should be taken in laying out and conducting a program. It is not always possible to set up a complete program at the start; often the results of the first holes determine the location of later ones, so that competent field supervision is necessary. Drilling should be done by a competent driller with suitable tools, and under adequate technical supervision. As most drilling will be done by a contractor, the specifications should be carefully drawn up. Rather than letting a contract on a straight footage basis, it may be desirable to break the contract down into several items, such as a lump sum for moving into the area, a footage charge for drilling hole and collection of samples, a charge for collecting water samples, etc. This method will permit the contractor to earn a reasonable profit, no matter what type of work is done, and will prevent excessive bids on a footage basis in order to guarantee a profit. At times a per diem contract may prove more desirable because of its flexibility and ease of execution. Where shallow ground water is to be observed for level and water quality, observation wells have frequently been constructed by means of a post-hole auger or similar tool and cased with stove pipe or other light metal casing.

The most important item in test drilling is the collection of formation samples. The usual procedure is to collect a sample every 5 or 10 feet and at every change in formation. The field man should make sure that the samples are accurately taken and labeled. The driller should keep his own log for comparison later with the sample log. Sometimes it may be desirable to have the driller keep a "time" log (the time per foot drilled), or to have an electric log made of the hole. It may also be desirable to collect water samples from the various water-bearing horizons penetrated. Various methods have been used to collect water samples to fit the many different conditions. In some cases a sampling device in the open hole is satisfactory; in others, casing has to be installed and the hole has to be pumped before a reliable sample can be obtained.

Another by-product of test drilling is the conversion of the test hole into an observation well by proper casing and finishing. Such a well is usually ideal in that it can be properly located, and there is no doubt as to the water-bearing horizon penetrated, and little likelihood that the well will be destroyed or put into use after a few measurements have been made in it. Wells drilled for geologic and chemical data or for observation purposes may also be used for pumping tests. They may also be useful for obtaining data for studies of drainage problems.

PUMPING TESTS

.18 The behavior of the water table or piezometric surface of an aquifer depends upon the discharge from or recharge to the aquifer and the physical aspects of the aquifer: its permeability, its coefficient of storage, and its boundaries.

PUMPING TESTS (Cont.)

Properly conducted pumping tests are the most reliable means of obtaining estimates of the permeability and coefficient of storage, without which no accurate estimates of economic yield, most economical well spacing, or future behavior of the aquifer can be made.

In recent years pumping tests have been made on wells in many different areas under a wide variety of conditions, and excellent results have been obtained. However, the indiscriminate application of the pumping-test method to the solution of all quantitative ground-water problems can lead to erroneous conclusions, and a knowledge of the limits of the methods is necessary for reliable results. Many different methods of conducting pumping tests have been evolved, and a discussion of them is not within the scope of this chapter of the Manual. Such a discussion may be found in Geological Survey Water-Supply Paper 887, "Methods for determining the permeability of water-bearing materials," by L. K. Wenzel, and in several papers prepared subsequently by the Ground Water Branch of the Geological Survey.

THEIS NON-EQUILIBRIUM FORMULA .19 Of the methods discussed, perhaps the most useful is the Theis nonequilibrium formula. It can be applied in numerous ways to both the drawdown and recovery of water levels due to pumping or artesian flow, using one or several pumped wells and one or several observation wells. The Theis formula is a mathematical expression of the shape of the cone of depression of a discharging well at all times after discharging is begun. After measuring the shape of the cone of depression for a short period of time, the equation can be solved for the transmissibility and coefficient of storage. From these two constants the future drawdowns at different places in the aquifer can be computed for assumed rates of pumping by the same formula, ★subject to the assumptions given in Subparagraph 2.3.22A.★

PHYSICAL YIELD LIMIT .20 A determination of the physical yield limit will define the upper limit to be considered in studies for determining economic yield. Otherwise, a determination of the physical yield limit is usually of little direct practical value for studies of water supply for irrigation or other uses, since it does not include consideration of the economics of the recovery of water. It should be noted, however, that for some purposes the value of the water may be so high that the economic yield will approach or equal the physical yield limit.

ECONOMIC YIELD .21 In the determination of the economic yield of an aquifer, there are many factors which must be considered; some are entirely physical and some entirely economic. In attempting to determine the physical factors, two quantitative functions of aquifers must be recognized and differentiated. Some aquifers function chiefly as reservoirs and some as underground conduits, but all of them have some of the properties of both. Methods based on the reservoir concept are applicable chiefly to water-table conditions, and methods based on the conduit concept are applicable mainly to artesian conditions in which the water moves laterally considerable distances from the intake to the discharge area. The storage concept, which has many merits since water losses are negligible and available storage capacities usually are large, utilizes the idea of an aquifer as a reservoir, the economic yield of which is equal to the recharge minus the discharge that cannot be salvaged by drawing down the water table, through pumping, to but not below, the economic level.

The flow concept envisions the aquifer as a conduit, the economic yield of which is equal to the amount of water that could be transmitted through the aquifer under the gradients existing when the water level or piezometric surface at the point of discharge is lowered to the economic pumping level, provided the recharge to the aquifer is adequate to maintain that rate of discharge.

Various methods of estimating the economic yield have been devised, using either or both of these concepts, and an excellent summary of these methods is given by Meinzer in Geological Survey Water-Supply Paper 638-C, "Outline of methods for estimating ground-water supplies." More recently the method

ECONOMIC YIELD (Cont.)

of estimating future drawdowns by the Theis nonequilibrium formula has been widely used in estimating economic yields and, when applicable, has given reliable results.

One of the difficulties in reaching an estimate of the economic yield is proper appraisal of the economic and physical factors that may change from time to time. The economic pumping level may change considerably during a period of time. Improved pumping equipment or decrease in power costs might increase the economic pumping lift. Increase in power costs or the availability of new sources of water might decrease the economic pumping lift. Also, the amount of water that can be economically withdrawn from storage in the period of time before the water levels decline to the economic limit may be very much greater than the amount that can be pumped after the water levels have reached the economic pumping level. In some cases the amount of water in storage is so large that withdrawals greatly in excess of the recharge, as defined above, can be made for a long period of time with only a gradual but a continual decline in water levels. A good example of this is the High Plains area in Texas, south of Amarillo. Some artesian aquifers with high heads may yield large amounts of water to wells for many years before the water levels decline to the economic pumping level. Any estimate of economic yield must be qualified considerably to prevent mistaken applications.

GROUND-WATER PROBLEMS

.22 Because ground-water conditions depend on so many factors, each particular investigation will have its own special problems, no two of which are exactly alike. It is the purpose of this section to discuss only a few of the most common problems and their solution.

Interference of Wells

A. One of the common problems encountered in the use of ground water is that caused by the decline of water levels through interference among wells. Interference occurs when two or more wells are located so close together that their individual cones of depression overlap during pumping. Such interference causes the water level in each well to decline or the discharge to be reduced, or a combination of both. The prevention of all interference between wells is rarely possible, so that the matter of spacing of the wells becomes one of the relationship between the advantages of reduction of interference to the advantages of closer spacing. When objectionable interference occurs it may be necessary to abandon one or more wells and to locate replacement wells farther away from the others. When conditions permit, the lowering of the pump bowls to below the lowest expected water level may provide a solution but will necessitate an increased pump lift.

The best solution for interference is to determine the proper spacing at the beginning of the project. The testing of existing wells and others as they are being drilled provides data for the design of spacing and the revision of locations. Pumping tests should always be conducted before well-drilling equipment is moved away from new wells,or contractors released. Results of such tests should be used wherever possible in the selection of permanent pumping equipment. The drawdown caused by pumping may be determined at any point on the drawdown curve by the Theis nonequilibrium formula (see pages 87-89, Water-Supply Paper 887). This formula is based on the following assumptions:

(1) The water-bearing formation is homogeneous and isotropic.

(2) The formation has an infinite areal extent.

(3) The discharge well penetrates the entire thickness of the formation.

(4) The coefficient of transmissibility is constant at all places.

(5) Water taken from storage by the decline in water level is discharged instantaneously with the decline in head. Actual conditions differing from these assumptions will alter the results of the computations which must be adjusted accordingly.

Interference of Wells (Cont.)

For the nonequilibrium method it is desirable that there be sufficient observation wells to determine the drawdown curve. However, one well in addition to the pumped well may give satisfactory results. The coefficients of storage and transmissibility of the aquifer can then be computed. Knowing these values the drawdown at any point in the drawdown curve can be computed under any assumed conditions of pumping. If it is not practicable to install the observation wells, the transmissibility of the aquifer may be computed by the Theis recovery method (see pages 95-96, Water-Supply Paper 887). By this method, only the pumped well is needed for observations and the transmissibility is computed by the rate of recovery of the water level in the well. With this information and assuming a value for the coefficient of storage, the interference among wells may be estimated by substitution in the Theis nonequilibrium formula. The second method, though not as accurate, provides a working basis which may be checked and revised by additional pumping tests as development proceeds.

Rate of Flow into Wells

B. Although adequate water may be available in the ground-water source, problems may be encountered because the aquifer may not yield the water to individual wells at a rate sufficient to meet the requirements for use. The solution of this problem may be difficult. When the boundaries of the aquifer, its thickness and transmissibility can be determined (assuming the aquifer is homogeneous), the discharge of the proposed wells can be estimated from the specific capacity of existing wells or test wells and the drawdown estimated for the proposed wells. The specific capacity of a well is dependent to a great extent on the "development" of the well. ("Development," as used here, is the term applied to the treatment given a well to increase the flow of water into the well.) The size of the well also may be a factor. The water yield of wells under identical conditions are not in proportion to their diameter. As an example, under identical conditions, a well having a diameter four times that of another ordinarily would produce roughly 20 percent more water. Some good information on this matter is given in the book "Ground Water, its development, uses and conservation" by E. W. Bennison (see Paragraph 2.3.6). Having information on the extent, storage coefficient, and transmissibility of the aquifer and assuming values of the specific capacity, drawdown, and time of pumping, the yield of a well or group of wells may be computed by the Theis non-equilibrium formula. This information will then provide an estimate of the maximum economical rate at which water can be supplied by the wells.

Overdevelopment

C. The term "overdevelopment," although widely used, may be somewhat vague in meaning. In its strictest sense, overdevelopment is the result of more water being removed, on the average, from the ground-water reservoir than is supplied to it as recharge, thus causing a continuing decline in water levels or artesian pressure. In general, overdevelopment, in this sense, is undesirable, but there are conditions under which it is permissible, or even desirable (see Continuous Depletion Rate, below). Continued overdevelopment of an aquifer will eventually draw the water level or artesian head down to where it is no longer economically feasible to continue the use of water at the present rate. Hence, a reduction of use will be necessary, eventually. When referring to a declining water level, or artesian pressure, as an indication of overdevelopment, it is necessary to consider whether the decline is a continuing one or is only temporary. Two types of decline may be noted in an aquifer, yet not indicate overdevelopment: the first and most common is that due to minor reductions of water supply (as during droughts), which will eventually be compensated for by increases; the other is the initial lowering that is experienced before the aquifer stabilizes to the demand placed upon it.

Continuous Depletion Rate

D. The continuous depletion rate has been defined as the average rate over a period of years at which artificial withdrawals continuously deplete the storage in a ground-water reservoir in which the annual recharge is small compared to the total quantity of water in storage. The outstanding example of a reservoir with a high depletion rate is that underlying the High Plains of northwestern Texas and adjacent states. The withdrawals are very large,

compared with the recharge, but the storage is so large that withdrawals at this rate may continue for many years, without seriously depleting the supply as a whole, although in heavily developed localities depletion may occur fairly early and then spread gradually to surrounding areas.

E. The economic yield of an aquifer may be limited by its transmissibility (its capacity to transmit water). Under these conditions the economic yield of a local area may be exceeded as a result of too many wells in the vicinity. This condition is often found in heavily industrialized areas or in areas of intensive agricultural use of water. It cannot be clearly distinguished from a problem of interference of wells as it is only a slightly more severe condition resulting from the same basic problem. The solution of this problem may be difficult but the following methods have been used successfully: Local Overdevelopment

(1) The reduction of pumping demands by the substitution of other sources of supply. These other sources may either be surface water or water from wells outside the overdeveloped area.

(2) The curtailment of pumping operations.

(3) Artificial recharge within the area of influence of the wells.

F. The economic yield of an entire aquifer may be exceeded. When this occurs it is due to the lack of recharge rather than to a low transmissibility. The effects of general aquifer overdevelopment are widespread and are likely to affect a greater number of individuals. The solutions to this problem are somewhat similar to those for local overdevelopment, except that the substitution of water from other sources may be more difficult and the use of artificial recharge may be more desirable. Aquifer Overdevelopment

G. In cases where the aquifer supplying water is located near the ocean or other bodies of saline water, particular care must be taken in developing or increasing the quantity of water withdrawn; otherwise salt water may be drawn into the fresh-water area, contaminating the supply. Basically, one of the problems of salt-water encroachment is due to upsetting the natural balance between the fresh and salt water. Because of the difference in specific gravity between the two, the fresh water tends to float on top of the salt water. Roughly the ratio of specific gravities of fresh to sea water is 40 to 41, that is, 41 feet of fresh water is required to balance 40 feet of salt water. Considering the ideal case of an island of uniformly permeable material in the ocean ★with ground water under water table conditions,★ for every foot of fresh water above the sea level there will be 40 feet of fresh water below sea level but on top of salt water. ★Should the head of fresh water above sea level be lowered, the boundary between fresh and salt water will rise. For every foot of lowering of the fresh water table, the boundary will rise 40 feet. The time it will take for the boundary to rise will be dependent on the depletion rate at which the water is withdrawn from storage, and the permeability of the aquifer.★ Practically, the theory is modified by the physical characteristics of the various aquifers and by the fact that some mixture of salt and fresh water occurs. There has been encroachment of salt water at places along the Atlantic and Pacific Coasts and the Gulf of Mexico. One example is the Los Angeles area of California, where in some places wells as far as 20 miles inland have had to be abandoned. The solution of most of these problems is the maintenance of the fresh-water head at a height sufficient to keep the salt water below the intakes of the wells. Some wells may have to be abandoned, or their discharge reduced, to accomplish this. In areas where the fresh-water head is low, long shallow galleries or ditches are dug at the level of the water table. Relatively large quantities of water can be discharged by lowering the head only a few inches and "skimming" the fresh water from the top. Contamination

Another type of salt-water encroachment is caused when the flow of surface streams or canals entering the ocean becomes low enough for tidal sea

Contamination (Cont.)

water to move upstream and enter the zone of saturation. Usually this occurs during only a short period, and the salt water enters the zone of saturation in a more or less homogeneous body which may move a considerable distance inland from the stream or canal. Wells within this area would be contaminated, and if a well field is located nearby the whole body of salt water may move in that direction. This has occurred in several places, notably in Miami, Florida, where the course of several of these incursions of sea water has been traced up the Miami Canal and into the well field, although there has also been an upset of fresh salt-water balance due to the lowering of the water table. The solution to the problem again lies in the maintenance of head in the streams to prevent the salt water backing up in the channels. Low-water dams have been successful in some places. Other control of stream flow also may succeed in keeping the head high enough to prevent salt-water encroachment. Location of well fields as far as possible from the streams may also be helpful.

Problems of salt-water encroachment may occur where waters of different types occur in the same area. This may take place in aquifers where the connate water (water laid down in the formation while it was being deposited) or other mineralized water has not been completely flushed out by fresh water entering the outcrop. Generally the line of demarcation between fresh and mineralized water is not sharp but mineralization increases with the distance down dip, and a zone of marginal water exists between good water and water too highly mineralized to be suitable for most uses. A well located in or near the marginal zone may produce good water for a time, but as the cone of depression expands it reaches the zone of mineralized water and as water is drawn from farther and farther within this zone it gradually becomes more mineralized until it is unfit for use. The solution to this problem is to reduce the discharge or locate the well farther up dip. Reduction in discharge will delay but generally will not stop the increasing mineralization unless the head down dip has recovered sufficiently. In water-table areas a variation of the above problem may occur, especially in the alluvium of some of the major streams in the West where mineralization increases with depth. Here the water near the base of the alluvium may be quite unfit for irrigation or other uses, but the upper part of the zone of saturation may contain suitable water. Wells that only partially penetrate the aquifer and are not heavily pumped may supply sufficient water for irrigation, without drawing from the deeper heavily mineralized waters. The principal sources of recharge would be from irrigation, induced infiltration from streams, or from rainfall.

In addition to the cases mentioned above, contamination from oil-field brines, factory wastes, mine waters, sewage, and other sources has occurred in various parts of the country. Unfortunately, the contamination of ground-water reservoirs from such sources does not often show up immediately and when the contamination is discovered, perhaps many years later, the damage cannot be repaired, or its correction will require a very long time. One solution of the problem is to maintain water levels so that the flow from the point of contamination will not be toward the point of use. This involves the curtailment of use to the extent that the proper levels are maintained. Adequate disposal practices, initiated early in the development of the industry, mine, or other source of contamination, are the best means of preventing such problems. Oil-field brines can be put back into the ground below the fresh-water horizons through disposal wells; and factory wastes, sewage, and mine waters can be treated for removal of harmful ingredients before disposal, preventing any contamination of ground-water reservoirs.

★★★

Chapter 2.4 of this Volume is devoted to the matter of the quality of water, and discusses the general problems and the specific studies involved. Chapter 4.6 is devoted to studies of the water requirements for salinity control. Each of these portions contain information that may be useful in studies involving ground-water contamination.

H. All ground water contains a certain amount of mineral matter which has been taken into solution during percolation through the rocks, the amount depending on such factors as the type of rock, water temperature, and the time and distance of travel. Evaporation and transpiration of all or part of this water will redeposit the material or increase the concentration of these salts. Irrigation practices therefore tend to increase the concentrations of these salts and repeated re-use of such water may result in a water having a concentration exceeding the tolerance of the crops. The solution to such a problem is to permit sufficient water to flow out of the area to carry off the excess salts. Thus salt concentration may definitely limit the amount of water available for irrigation. At times it may be practical to combine saline ground water with fresh surface waters to provide a usable supply. This problem is further discussed in Chapter 4.6, and problems of water quality are discussed in Chapter 2.4. Salt Concentration

.23 Artificial recharge of ground-water reservoirs has been successful in many parts of the country. Artificial recharging not only replenishes the ground-water reservoir but conserves water that might otherwise run off to the ocean without benefit, or be consumed by native vegetation. Recharge through wells or through water spreading are both possible. In irrigation work, water spreading is the most common method of adding water to the ground-water reservoirs. The practice is somewhat similar to an irrigation system except that no attempt is made to grow a crop. In fact, frequently the spreading areas are kept clear of vegetation and the surface is systematically scarified to increase the percolation rate. Such spreading works may consist of a diversion dam and canals leading to a series of diked areas to form ponds on permeable ground, or may be merely a series of crude ditches fanning out from a stream to flood land not otherwise used, except possibly as grazing land. In some localities the water-spreading devices serve the purpose of flood abatement as well as ground-water recharge. Such works should, of course, be designed to require a minimum of work to operate and maintain. Watershed treatment such as employed for soil conservation purposes, including terraces, contour furrows, vegetative cover, etc., will be quite effective in areas of permeable soils. Such practices retard the runoff and allow greater time for the infiltration of water into the ground and its downward percolation. Occasionally it is practical to construct a storage dam and reservoir at a site in the intake area so that water is retained on permeable ground where the leakage will become part of the ground water. Usually such reservoirs also serve for flood control and occasionally even as storage for surface uses. Where land values are high and water is costly, wells are frequently employed as a means of artificial recharge. In this practice, wells are sunk into the aquifer so that they will permit water to flow rapidly into it. Such wells usually require casing to prevent collapse and the erosion of the side walls. However, in some formations this is not necessary or is necessary for only part of the depth. In some installations the wells have been filled with coarse, screened gravel rather than cased. The gravel serves to support the well and to prevent erosion of the walls. This method would be especially unsatisfactory where there is an opportunity of fine material being carried into the well to clog the gravel. Frequently a pit or pond is employed at the top of the well to impound water so that the well will operate at the maximum rate. Water may be diverted to the wells by means of ditches or they may be used in stream beds or in areas of considerable surface flows. They are frequently used in connection with the other methods of artificial recharge discussed above, in order to speed up the flow of water into the aquifer. MEANS OF ARTIFICIAL RECHARGE

.24 Depending upon local conditions, several means may be employed to bring the water to the surface. The most common is the use of wells and pumps. Such wells may be dug, drilled, or driven as the conditions warrant. Because this form of development is so well known and is adequately covered in standard texts, it need not be discussed in detail here. Where wells do not provide an adequate amount of water or where the natural conditions dictate, galleries may be employed to collect the ground water and lead it to a pump or to a gravity diversion to the surface system. Such galleries may be constructed by tunnelling or widening out from a vertical shaft, by cut and cover, by tunnelling DEVELOPMENT OF GROUND-WATER SUPPLIES

DEVELOPMENT OF GROUND-WATER SUPPLIES (Cont.)

from a lower level, or by open cut. In some instances they have been constructed by forcing porous pipe, or drilling, into the formation from a pit or lower level. They are usually located in sandy or gravelly river-bed materials or in porous rocks, such as the volcanic rocks of the Hawaiian Islands. When in soils, sand or gravel, the galleries usually must be lined to prevent collapsing. The linings may be in the form of cribbing, porous plates, perforated or porous pipe, or any other material that will permit the entrance of water yet provide the strength required to support the materials around the gallery. Tunnels may also be employed in a manner that cannot be classed strictly as galleries. In this method a tunnel is driven through nonwater-bearing formations to tap formations or seams containing water. This usage is particularly common in the Hawaiian Islands, and is used in many places throughout the world. It is particularly useful in volcanic areas where perched water tables exist in lava with dikes and ash beds confining the water, to prevent or retard its escape. Usually tunnels are driven to the "dry face" of the dike that dams the water and drifts are cut along its face. Cuts are then made through the dikes into the water-bearing beds to release the water. Such cuts are frequently fitted with gates or valves to permit the regulation of the flow. This type of development might prove useful to tap underground channels, with the tunnel crossing the channel and an artificial dike or dam to divert the flow. The incidental accretions of ground water to tunnels constructed for other purposes are often valuable.

CUT-OFFS .25 Where considerable water is moving in underground channels, such as a gravel-filled river bed, it may be practical to construct a cut-off to bring the water back to the surface where it may be utilized as a surface flow. Such cut-offs may be dams or barriers constructed of concrete, masonry, or earth, similar in principle to the normal type of diversion or storage dam, or they may be sheet pile driven into place, or grout barriers.

Interior - Reclamation - Denver, Colo.

CHAP. 2.4 QUALITY OF WATER

.1 The purpose of this chapter is to present policies, standards, and procedures for quality of water investigations and interpretations of quality of water data needed in conjunction with the planning, construction, and operation and maintenance of irrigation projects by the Bureau of Reclamation. The discussions in this chapter relate entirely to the use of water for irrigation. The importance of quality of water with particular respect to land classification is outlined in Part 2 of Volume V. Quality of water relative to drainage is discussed in Chapter 10.3 of Volume VII. Water analysis of ground-water supplies is discussed in Chapter 2.3 of this Volume. Quality of water problems related to stream pollution are treated in the discussions in Chapter 4.5 of this Volume, and in Part 4 of Volume VII. Municipal, domestic, and industrial water supply problems are discussed in Chapter 3.3 of Volume VII and Design Supplement No. 11, Railroads, Highways, and Camp Facilities, of Volume X. Quality of water for use in mixing and curing concrete is discussed in the Concrete Manual. Salinity control is discussed in Chapter 4.6 of Volume IV. PURPOSE

.2 Quality of water as herein used is defined as the suitability of water for irrigation use. It is measured by the type and concentration of the dissolved and suspended constituents. The concentration of suspended constituents is considered only insofar as it influences the suitability of the water for irrigation, or the particular significance it may have in relation to project soils. Other suspended sediment load considerations are treated in Part 9 of Volume VII. DEFINITION

.3 The suitability or permissible composition and concentration of water for irrigation use is dependent upon a number of variable factors pertinent to specific localities, chief among which are the nature of the soils, drainage, water supply (quality), climatic conditions, irrigation practices, and tolerances of the crops grown. Surface and ground waters naturally contain varying amounts and kinds of dissolved constituents as a result of the solvent action of water on minerals and rocks encountered in flow. When the water is applied to land, a part is consumptively used, a part is held by the soil, and the remaining surplus, if any, moves downward or laterally through the soil and substrata. The retained water, or soil solution, generally becomes more concentrated in dissolved constituents through evaporation and plant utilization. The drainage waters also generally increase in concentration and the quality may be adversely affected for further use. In the planning of projects it is therefore essential that the quality of the potential water supply be carefully estimated with respect to: (1) the nature and concentration of various constituents, (2) its probable effects, if any, on the crops and soils of the project under varying rates of application and conditions of precipitation, (3) character of the return flow from the project lands, and its influence on the quality of downstream water supplies for use on other lands, and (4) methods and costs of improving and managing the supply. On existing projects, the quality of the irrigation, drainage and well, or other ground waters should be determined from time to time and the data applied in maintaining the suitability of water on the project. Adverse trends, sources of salinity, and contamination when pollution is a problem are important considerations in irrigated areas. GENERAL

.4 Quality of water will be considered or determined in all phases of irrigation project planning, development, and operation. Responsibilities of the Commissioner's Office in these determinations are contained in the functional statements for Project Planning and Operation and Maintenance Divisions, Part 3 of Volume I. The Regional divisions have functional responsibilities similar to their counterparts in the Commissioner's Office (Part 4 of Volume I). Field direction of the quality of water investigations for all phases is the responsibility of the operating office head. RESPONSIBILITIES

.5 A minimum of three factors must be known in order to make an estimate of water quality for irrigation use: (1) the total concentration of dissolved solids, (2) the relative proportion of sodium to other cations, and (3) the concentration of boron. Recognition of the significance of these factors has been based on experience.1/ Each must be correlated with the additional factors of soil FACTORS

1/ Wilcox, L. V., "The Quality of Water for Irrigation Use." U. S. Department of Agriculture, Technical Bulletin 962, 40 p., 1948.

characteristics, drainage, irrigation practices and crop tolerances for proper quality interpretations. The importance of considering other constituents and characteristics of water, such as turbidity and bicarbonates in determining suitability of water for irrigation varies from area to area. Certain of these other factors may also require careful consideration in specific areas. Particularly, the bicarbonates require correlation with calcium and magnesium during detailed studies of questionable water supplies.

Total Dissolved Solids

A. The quantity of total dissolved solids in irrigation water is very significant with respect to normal plant growth. Continuous use of water high in concentration of total dissolved solids will generally create a notable increase in the salinity of the soil solution. This may result in (1) reduced availability of moisture, and disturbed nutrition and metabolism of plants; (2) injury to root tissues; and (3) indirect effects on permeability of soil to water and air. If drainage is inadequate, soluble salts will accumulate in the upper soil layers and the development of unfavorable conditions will be accelerated. If good drainage exists and can be maintained, crop injury or yield limitations may not develop. Conversely, the presence of a sufficient amount of dissolved solids may insure the permeability of certain soils which would become impermeable under continuous use of less saline water.

Sodium

B. The relation of sodium to calcium and magnesium has particular significance in appraisals of the quality of water for irrigation use because of two well-recognized effects attributed to sodium. First, experience and research have shown that sodium has a deleterious effect upon soil structure by causing dispersion of soil particles. A common result is retardation of water and air movement through the soil and substrata and creation of unfavorable conditions for root growth and farm irrigation practices. Secondly, the roles of sodium in creating toxicity and high alkalinity in the soil system with deleterious effects upon crops and in suppressing the availability of certain essential nutrients are commonly recognized. The interaction of the sodium factor with such variables as soil texture, exchange capacity of the soil, drainage, and the amounts and types of other constituents in the water and soil, such as calcium carbonate and gypsum, is important in establishing the significance and permissible limits of sodium in the irrigation water. For example, if the concentration of total dissolved solids is low and the soils are coarse-textured, calcareous, very permeable and adequately drained, a larger proportion of sodium may be tolerated in the irrigation water than would be permissible for finer-textured, less well-drained soils. On the other hand, a high bicarbonate content might cause a so-called residual sodium carbonate problem, even though the sodium content is relatively low. An excess of bicarbonate over magnesium and calcium in water supplies which are sparingly used may favor development of this problem.

Boron

C. The importance of boron as a limiting factor in determining the suitability of irrigation water for continuous use has been established. This element is particularly troublesome for two reasons: it is toxic at relatively low concentrations; and, it may adversely affect growth of many specialized, high-priced crops, particularly fruits and nuts. For this latter reason, type of crop is one of the most important considerations in establishing the limiting specifications for boron in irrigation water. The injurious effects of boron are manifest by death of tissues, retardation of growth, and stunting of plants. Serious effects on size, quality, and yield of crop may result. As with sodium, consideration of the limiting effects of boron requires recognition of soil characteristics and drainage conditions. The onset of boron injury has been found more rapid on the coarser-textured soils, which are, however, more easily leached of boron and reclaimed when a better water supply is used. An additional factor relative to the boron problem is climate. Most plants appear to withstand higher boron concentrations in cool and humid weather better than under conditions conducive to high transpiration rates. However, lack of boron in soils and water can occasionally be related to limited crop growth, and a need for application of boron is possible.

SPECIFICATIONS

.6 General specifications for water quality have limited applicability, inasmuch as each locality is largely a problem in itself. The complex interrelationships of

water, soil, drainage, crop, climate, and irrigation practice limit the value of the various classifications of irrigation water quality which exist. The classification of a water represents only a part of the quality evaluation. Determining how the water may be used is the ultimate objective of water quality studies. It is essential to recognize, therefore, that any of the standards should be used with reservation and understanding, and that specific evaluations of questionable water must be made subsequently on the basis of local conditions, laboratory and field tests, and experience. One of the earliest systems for classifying irrigation water was offered by Stabler in 1911.2/ More recent systems for classifying irrigation waters were suggested by Wilcox,1/ and Thorne and Thorne.3/ The United States Salinity Laboratory has recently offered a classification which embodies certain desirable features of the other systems and is acceptable for use as a guide in making preliminary evaluations.4/ The classification is described briefly below. The selection of limits was based on research and general irrigation experience. The tentative aspect of the classification cannot be overemphasized.

SPECIFICATIONS (Cont.)

A. Waters are divided into four classes with respect to "conductivity," the dividing points between classes being at 250, 750, and 2250 micromhos/cm. (see Illustration 1). The classes are described as follows:

Salinity Hazard

C1 Low-salinity water can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required but this occurs under normal irrigation practices, except in soils of extremely low permeability.

C2 Medium-salinity water can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

C3 High-salinity water cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required, and plants with good salt tolerance should be selected.

C4 Very high-salinity water is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching and very salt-tolerant crops should be selected.

B. The relative proportion of sodium to other cations in an irrigation water is expressed in terms of "sodium-adsorption-ratio" (SAR) which is defined by the equation:

Sodium Hazard

$$SAR = Na^{+}/\sqrt{(Ca^{++} + Mg^{++})/2}$$

where Na^{+}, Ca^{++}, and Mg^{++} represent the concentrations in milliequivalents per liter (m.e./l.) of sodium, calcium, and magnesium, respectively. The sodium-adsorption-ratio is more significant for interpreting water quality than the "percent π sodium" formerly used because it relates more directly to the adsorption of sodium by the soil. A nomogram for estimating the SAR value of an irrigation water is shown in Illustration 2. The SAR value may be calculated from the above equation or estimated by use of the nomogram. A very preliminary estimate of the exchangeable sodium percentage which

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2/ Stabler, H., "Some stream waters of western United States." U. S. Geol. Survey Water-Supply Paper 274, 188 pp., 1911.

3/ Thorne, J. P. and Thorne, D. W., "Irrigation Waters of Utah, their quality and use." Utah Agr. Exp. Sta., Bull. 346, 64 pp., 1951.

4/ U. S. Salinity Laboratory Staff, "Diagnosis and improvement of saline and alkali soils." U. S. Dept. Agr. Handbook (in process), 1953.

Sodium Hazard (Cont.)

may result in a well-drained soil at equilibrium with the irrigation water may be read on the D scale. Waters are divided into four classes, with respect to sodium hazard, the dividing points being at SAR values of 10, 18, and 26 (see Illustration 1). The classes are described as follows:

S1 Low-sodium water can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stonefruit trees and avacados may accumulate injurious concentrations of sodium.

S2 Medium-sodium water will present an appreciable sodium hazard in fine-textured soils having high cation-exchange-capacity, especially under low leaching conditions unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.

S3 High-sodium water may produce harmful levels of exchangeable sodium in most soils and will require special soil management: good drainage, high leaching, and organic matter additions. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible in the case of waters of very high salinity.

S4 Very high-sodium water is generally unsatisfactory for irrigation purposes, except at low and perhaps medium salinity where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

Boron

C. Boron is present in practically all waters. It is essential to plant growth, but is exceedingly toxic at concentrations only slightly above optimum. The permissible limits for boron vary largely with crop sensitivity, and are summarized in Table 1.

TABLE 1
PERMISSIBLE LIMITS FOR IRRIGATION WATER 1/

Classes of Water		Boron, parts per million		
Rating	Grade	Sensitive Crops	Semitolerant Crops	Tolerant Crops
1	Excellent	0.33 or less	0.67 or less	1.00 or less
2	Good	0.33 to 0.67	0.67 to 1.33	1.00 to 2.00
3	Permissible	0.67 to 1.00	1.33 to 2.00	2.00 to 3.00
4	Doubtful	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
5	Unsuitable	1.25 or more	2.50 or more	3.75 or more

Residual Sodium Carbonate

D. The effect of bicarbonate ion concentration on water quality is expressed in terms of "residual sodium carbonate" which represents the amount of bicarbonate plus carbonate remaining after deduction of calcium and magnesium. Residual sodium carbonate (RSC) is defined by the equation:

$$RSC = (HCO_3^- + CO_3^=) - (Ca^{++} + Mg^{++})$$

where HCO_3^-, $CO_3^=$, Ca^{++} and Mg^{++} represent the concentrations in milliequivalents of bicarbonate, carbonate, calcium and magnesium ions, respectively. Waters with more than 2.5 m.e./l. of residual sodium carbonate tentatively are not considered to be suitable for irrigation. Waters containing 1.25 to 2.5 m.e./l are marginal, and those containing less than 1.25 m.e./l. are probably safe.

Crop Tolerances

E. The relative tolerance of crop plants to soluble salts and to boron is an important consideration in applying the specifications. Groupings of crops according to relative salinity and boron tolerance are presented in Tables 2 and 3.

TABLE 2
THE RELATIVE TOLERANCE OF CROPS TO DISSOLVED SOLIDS
IN THE SOIL SOLUTION 4/

Crop Tolerances (Cont.)

Sensitive	Semitolerant	Tolerant
Grapefruit Pear	Pomegranate Fig	Date palm
Apricot Almond	Grape Olive	Sugar beet
Peach Plum	Alfalfa	Garden Beet
Apple Orange	White and Yellow sweet clovers	Milo
	Strawberry and Hubam clovers	
Lemon	Perennial rye grass	Asparagus
	Dallis and sudan grasses	
White Dutch clover	Mountain brome	Rape
	Orchard grass	
Meadow foxtail	Blue grama	Kale
	Meadow fescue	
Alsike and red clovers	Perennial rye grass	Cotton
	Reed canary	
Ladino clover	Birdsfoot trefoil Sour clover	Alkali Sacaton
	Smooth brome	
Vetch Burnet	Tall meadow oat grass	Salt grass
Celery	Sickle and Cicer milk vetches	
Arichoke	Oats Foxtail millet	Nuttall alkali grass
Egg Plant	Sorghum Wheat	Bermuda grass
Sweet potato	Rice Rye	Rhodes grass
Potato	Cantaloupe Tomato	Rescue grass
Green beans	Lettuce Cauliflower	Canada wild rye
Spinach	Sunflower Corn	Beardless wild rye
Radish	Carrot Peas	Western Wheat grass
	Squash Cabbage	
	Onion Potatoes (White Rose)	
	Pepper	
	Barley	

Crop Tolerances (Cont.)

TABLE 3
RELATIVE TOLERANCE OF CROP PLANTS TO BORON 5/

Sensitive	Semitolerant	Tolerant
Lemon	Lima bean	Carrot
Grapefruit	Sweet potato	Lettuce
Avocado	Bell Pepper	Cabbage
Orange	Tomato	Turnip
Thornless blackberry	Pumpkin	Onion
Apricot	Zinnia	Broadbean
Peach	Oat	Gladiolus
Cherry	Milo	Alfalfa
Persimmon	Corn	Garden beet
Kadota fig	Wheat	Mangel
Grape (Sultanina and Malaga)	Barley	Sugar beet
Apple	Olive	Palm (Phoenix canariensis)
Pear	Ragged Robin rose	Date palm (P. dactylifera)
Plum	Field pea	Asparagus
American elm	Radish	Athel (Tamarix aphylla)
Navy bean	Sweet pea	
Jerusalem-artichoke	Pima cotton	
Persian (English) walnut	Acala cotton	
Black walnut	Potato	
Pecan	Sunflower (native)	

ANALYSIS OF EXISTING DATA

.7 In order to determine the need for and extent of investigations necessary, the available data must be examined and interpreted insofar as possible considering the limiting specifications for quality of irrigation water. One of the primary sources of such data are the Water Supply Papers of the United States Geological Survey. Other sources include the State Health and Public Work Departments, agricultural experiment stations, and the Department of Agriculture. The water analyses data which are in the files of Federal Agencies should be consulted. 6/ There are two outstanding limitations in the utility of most existing data: the sampling in the earlier studies was generally inadequate; and, the method of reporting results and type of analyses often do not meet present requirements. In many cases, however, indications of the major problems, if any, to be anticipated in quality of water investigations can be derived to plan for more intensive studies when necessary, and provide a basis for establishment of specifications for water quality and use in a particular area.

PROGRAM DEVELOPMENT

.8 Following analysis of any existing data, a plan for investigations must be prepared. Studies directed toward determination of quality for irrigation use, require careful correlation with concurrent and subsequent related investigations and surveys. Particularly, the program of investigation should be prepared in consideration of hydrologic studies, and subsequent drainage and land classification surveys, or in coordination with such current surveys. Cooperative work with the Geological Survey should be arranged whenever possible and the Water Quality Network of the Subcommittee on Hydrology, FIARBC, used insofar as possible. For these reasons, the program should be jointly prepared

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5/ Eaton, F. M., "Boron in Soils and Irrigation Waters and its Effects on Plants, with Particular Reference to the San Joaquin Valley of California." U. S. Department of Agriculture, Technical Bulletin 448, 60 p., 1941.

6/ "Inventory of Published and Unpublished Chemical Analyses of Surface Waters in the Western United States." Federal Inter-Agency River Basin Committee Notes on Hydrologic Activities, Bulletin Number 2, 65 p., mimeographed, October 1948.

by hydrologists, drainage engineers and land classification specialists under proper direction. The general specifications in Paragraph 2.4.6, and those for land classification in Part 2 of Volume V will be correlated, and may be modified to fit special conditions in the area involved. An outline, including location of sampling stations; time, depth, and frequency of sampling; size of samples; equipment and precautions for sampling; type of and arrangements for analysis; and personnel responsibilities will be prepared.

COLLECTION OF SAMPLES--GENERAL

.9 The collection of samples is an important procedure requiring careful planning and technique by the hydrologist. Obtaining representative samples and avoiding contamination are the two principal considerations. Requirements to obtain representative samples vary with the types of problems, but contamination must be avoided without exception. This can be accomplished only by the use of thoroughly cleaned containers, preferably glass or plastic bottles. As a further precaution, the container must be rinsed with the water to be sampled. It is then refilled, leaving space for expansion, securely stoppered, and labeled. Special sampling devices and techniques may be used (see Chapter 9.3 of Volume VII), or the samples may be obtained by any other reasonable method. The size of sample will vary, depending upon the type and method of analysis contemplated. An 8-ounce sample has proved adequate for determination of percent sodium and total dissolved solids, if a flame photometer procedure and the conductance method are used in the laboratory. One-quart samples are required for the complete analysis outlined in Paragraph 2.4.10; but if the analysis is to include trace elements, a larger sample will be required. The size of larger samples will be specified by the laboratory which will perform the analyses. The label must show at least the sample number, and the date and time of collection. A more detailed description must be prepared to forward with the sample to the laboratory and for later use in interpretation of results. Shipment of samples is generally required, and adequate precautions must be taken by proper packing to avoid breakage or contamination due to handling, delay, or extreme temperatures. Samples can be most easily shipped in bottles of polyethylene-plastic composition. When shipped in this manner the samples do not need to be protected against temperature extremes, or packed with padding to prevent breakage. When the analyses are to be made in the Bureau's chemical laboratory in Denver, bottles and shipping containers will be made available upon request to the Chemical Engineering Laboratory Section, Design and Construction Division. The request should indicate the size of container or type of analysis desired, and the number of bottles required. Detailed procedure for collection of samples for specific cases is described below.

Flowing Surface Waters

A. Flowing surface waters must be sampled with respect to characteristics of flow. Quality and quantity must be correlated for adequate interpretations of long time effects of use for irrigation. Two types of sampling will generally be conducted: spot samples will be obtained for preliminary appraisals of general quality, such as are needed when no data exist; and detailed sampling will be conducted when a need for more extensive studies is indicated on the basis of existing data or spot sampling data which show possibility of a questionable supply. Detailed sampling stations should be established at significant locations, generally gaging stations, where simultaneous discharge data will be obtained for each sample. Flows of main streams and important tributaries, flows contributing to storage supplies, flows at points of diversion, canal flows and drain flows must be periodically sampled. The time and frequency of sampling will be governed by characteristics of flow, and may vary between stations according to their importance. Whether samples are taken once a day, once a week, or once a month, care must be taken that they represent the discharge at the time.

(1) Several samples for consecutive days may be mixed together for a composite sample if the variation in discharge from day to day is small and if individual samples show differences in conductance of not more than 30 percent of the mean for the period. Generally a minimum of three composites a month consisting of equal volumes of approximately 10 daily samples each will be prepared. In other cases, the amount of each individual sample which is included in the composite must be

Flowing Surface Waters (Cont.)

proportional to the discharge of the stream at the time the samples were taken. Composite samples of representative high and base or low flows are a minimum requirement for most flowing waters. Samples of flow generally will be obtained at each station over a minimum period of 1 year.

(2) Flood discharge samples cannot be composited, and floods must be sampled when they occur. The number of samples collected of each flood will depend upon its intensity. Those of short duration will be sampled at, or near, the crest, while those extending over a period of a week or more will be sampled on the rising stage, at the crest, and on the receding stage.

(3) Additional samples should be collected whenever there is reason to believe the quality has changed, even though the stage may remain unchanged. Seasonal and climatic effects produce wide variations, especially in smaller streams, and therefore, the frequency of sampling is an important phase of the procedure. Spot samples of small side drainages often prove useful in diagnosing main stem quality changes due to such accretions.

(4) The samples should be representative of actual conditions, that is, they should be collected from the main section of the stream, or that portion representing the greatest discharge at the time of sampling. Experience has shown that the samples should be taken from approximately six-tenths the depth of the section. Collection of samples near the bank of the stream, or from isolated pools should be avoided because they are not representative of actual flows. The advisability of using depth-integrating and other procedures will depend upon the quantity of flow or size of stream.

(5) A record supporting the samples will be prepared on a suitable form (Illustration 3). A copy of the record should be forwarded with the samples to the laboratory.

Surface Waters in Lakes, Ponds, Reservoirs, & Springs

B. The procedure for collecting water samples from lakes, ponds, reservoirs, springs, and the like is generally less involved than for flowing streams. In exceptional cases periodic sampling may prove desirable, but usually a few samples will suffice if properly obtained. Depth-integrated sampling procedures are recommended to provide representative, composite samples. Inflow as well as discharge at the spillway or other outlet may also be sampled. Containers should be labeled as previously directed. The record of supporting data should include the following information:

Sample number

Date and time of sampling

Location and depth of sampling

Stage of water (gage reading or other indication of water level and volume)

Discharge in c.f.s., if sample of a flow is taken

Additional remarks

Collector's name and address.

Ground Waters

C. Samples of ground waters (see Chapter 2.3 of this Volume) may be collected from shallow, deep, and artesian wells; drilled test holes; tile drains; and other sources of access. Ground waters are not generally subject to appreciable variation in quality except those occasioned by infrequent recharge.

Ground Waters (Cont.)

The characteristics, behavior and use of the ground water in an area will determine the sampling requirements, particularly the time, depth and frequency of sampling. Special care becomes necessary when sampling an operating well because it may be interconnected to one nearby or to a distribution system into which other wells may be discharging, or the water may have been standing in the casing for a sufficient period to cause stagnation or contamination. The collector should be sure that the pump is operating under conditions which permit taking a representative sample. Another problem of contamination occasionally encountered in older wells is that resulting from disintegration of the casing at higher levels by corrosive action of saline water in upper strata which then leak through and contaminate the lower supply. It is obvious that samples from wells not being pumped have questionable reliability. In any case, the informative record of a ground-water sample should include the following:

Sample number

Date and time of sampling

Sampling location

Description of well or other source of sample including description of profile and aquifers, depth of sampling, and depth supply is obtained from, condition of well casing, sources of contamination, pump discharge, and related information. (See Bureau Form 7-1426, Well Record and Chapter 2.3.)

Temperature of water at time of collection

Collector's name and address.

ANALYSIS OF SAMPLES

.10 The analysis of samples is a specialized procedure which must be performed by qualified chemists in laboratories equipped for water analysis. The minimum analyses required to ascertain quality of water for irrigation use include specific conductance, sodium, calcium, magnesium, and boron. The existing data will often provide an indication of the particular problems involved and the additional analyses necessary. In case the data are limited or lacking, it may be advisable to obtain several comparatively complete analyses on which to base further studies. A complete analysis for irrigation use suitability will include:

pH

Specific conductance (EC x 10^6 at 25° C) in micromhos/cm.

Total dissolved solids (T.D.S.) in parts per million

Cations--in parts per million (p.p.m.), equivalents per million (e.p.m.) or milliequivalents per liter (m.e./l.) of:

Calcium (Ca)
Magnesium (Mg)
Sodium (Na)
Potassium (K)
Iron (Fe).

Anions--in p.p.m., e.p.m., or m.e./l. of:

Carbonate (CO_3)
Bicarbonate (HCO_3)
Sulfate (SO_4)
Chloride (Cl)
Nitrate (NO_3)
Fluoride (F).

Boron (B)--in p.p.m.

~~ANAL~~YSES OF SAMPLES (Cont.)

Complete analyses add greatly to costs and should be held to a minimum. The pH determination of samples is a routine, simple analysis which should always be included. Total dissolved solids may be estimated from specific conductance determinations, or established gravimetrically. To obtain sodium absorption ratio, analyses for the major cations--Ca, Mg, and Na--are necessary. Newer, more direct methods permit a much simpler determination of sodium than was formerly possible. This factor can now be calculated from the value of sodium (as determined by use of the flame photometer) and the value of calcium and magnesium (as determined from a hardness titration). A boron analysis is advisable unless it has been established that boron is not a problem at a particular sampling station. All of the procedures used by the laboratory performing the analyses should compare in accuracy with those of the United States Salinity Laboratory. Arrangements for the analysis of samples can be made by the Regional Director with the Chief Engineer and existing Regional laboratories. Where special circumstances warrant, such arrangements may be made with other agencies such as the Quality of Water Branch, Water Resources Division, Geological Survey, the United States Salinity Laboratory, Riverside, California, State Boards of Health and State colleges. Specific instructions for handling and labeling the samples are generally provided by the laboratory director. The results of the analyses will be reported in a form similar to that shown in Illustration 4, though all items in the example will not necessarily be included, and others may be included.

ADDITIONAL ANALYSES & TESTS--SOILS & SUBSTRATA

.11 Interpretation of quality of water on the basis of the results of water analyses alone is not generally satisfactory in detailed types of irrigation use investigations. The need for special analyses and hydraulic conductivity tests of representative soils and substrata materials should be recognized, and such procedures undertaken during or prior to the detailed land classification survey. The more important analyses frequently required include those for salinity and alkalinity particle size distribution, gypsum, lime estimate, exchange capacity, exchangeable sodium and hydraulic conductivity of disturbed samples. It is particularly important, especially when border-line cases exist, that water having chemical and other characteristics similar to that of the existing or potential supply be used in the hydraulic conductivity tests. Descriptions of procedures for these tests are outlined in Chapter 2.10, Supplemental Procedures, of Volume V.

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COMPILATION OF DATA & COMPUTATIONS

.12 The types and amount of data collected during a quality of water investigation are diversified, and may become very complex. It is therefore imperative that a complete record of data be maintained by the field, area, or project office to support interpretations of suitability of the water supply for irrigation use. The data will generally include the following: (1) sample and sampling location descriptions and remarks; (2) results of water analyses; (3) results of soil and substrata analyses and hydraulic conductivity tests; and (4) supporting hydrologic data. Compilation of the data of the quality of flowing surface waters, considering their anticipated storage and downstream re-use, is generally the more complex of the various types of quality of water investigations.

If relatively few samples have been obtained, e.g. monthly samples of base flow, and special samples of flood flows, or if no correlation exists between concentrations of ions and discharge, the average character of the water supply can be calculated by: (1) determining the period runoff for each representative flow from the hydrologic data; and (2) computing a weighted average concentration of ions and total dissolved solids by proportioning the individual sample analyses over the annual discharge. Weighted average sodium adsorption ratio is computed by use of the weighted average concentration values of the cations. In detailed studies which have involved more frequent or daily sampling, the following general instructions or modifications thereof, should be followed where applicable. Conversion factors needed for the calculations will be found in various references 4/, 7/.

7/ "Scott's Standard Methods of Chemical Analysis," 5th Edition, Vol. 2, pp. 2087-2088. D. Van Nostrand Co. Inc., New York. 1939.

A. Plot the concentration of ions and total dissolved solids in parts per million against discharge (in c.f.s.) at each sampling station and construct curves by the least squares methods (Illustration 3, Chapter 8.1, this Volume) or other suitable means. Use a separate sheet of paper for each ion. The use of logarithmic paper (3 by 5 cycle) is generally advisable (see Illustration 5). Using values obtained from this curve construct a second curve on the same graph plotting tons per day against discharge (derive by computation: c.f.s. x p.p.m. x .0027). COMPILATION OF DATA & COMPUTATIONS (Cont.)

B. Compute the concentration in tons of ions and total dissolved solids accumulating each month (or other fixed period, and, assuming no depletion) by use of the above graphs and mean daily discharge at each sampling station (see Illustration 6).

C. Prepare a reservoir operation table (see Illustration 7) showing for each year the monthly (or periodic) variations in sodium and total dissolved solids. Proportion spills according to specific conditions anticipated or existing.

D. If advisable, because of downstream uses, divide the stream into significant reaches and show by months (or other periods) the anticipated or actual reservoir release, diversions, return flow, and natural accretions.

E. Compute the tons of ions and total dissolved solids anticipated, or remaining in the stream supply at the end of each reach every month (or other period) and compute sodium absorption ratio, conductance, and residual sodium carbonate 8/.

.13 The primary aim in the interpretation of quality of water investigation data should be directed toward an evaluation of the suitability of the water supply for use with specific lands, crops, irrigation practices and associated factors, which contribute jointly to agricultural production under irrigation. The interpretation is a correlation of the average composition and concentration of the water supply with the characteristics of the project lands in view of the proposed cropping practices and climate of the area. The interpretation may include specifically: sources of salinity and alkalinity; salt balance conditions on the projetc; physical and chemical deterioration or improvement of the soils; possible development of unfavorable drainage conditions; limitations in crop yields and adaptability; water treatment requirements; and the need for special irrigation or other practices. Several of the more common types of problems encountered are discussed below. Varying degrees of severity of the problems will naturally be encountered. The complexity of data and conditions, which can be encountered preclude establishing specific procedures for interpretations. Illustration 1 will provide a preliminary guide in many instances Recognition and evaluation of errors in sampling, analyses, and computations should be included with each detailed interpretation. INTERPRETATION OF RESULTS

A. Saline waters are those supplies which contain harmful concentrations of total dissolved solids, generally exceeding 20 equivalents per million, but the salts and soils are of such nature that sodium is not important. Experience has shown 9/ that use of the less favorable supplies requires: (1) assurance of good drainage to preclude increases in soil salinity; (2) the use of large quantities of water in irrigation practice to insure available moisture for the crops; and/or (3) growing of salt tolerant crops. To fulfill these conditions, the project soils, subsoils, and substrata must be open and Saline Water

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8/ Eaton, F. M., "Significance of Carbonates in Irrigation Waters." Soil Science 69:123-134, February 1950

9/ Refer to "The Salt Problem in Irrigation Agriculture," U. S. Dept. of Agriculture, Miscellaneous Publication 607, August 1946, and similar publications for details.

permeable. Drainage must be adequate to remove the water in excess of plant requirement applied to prevent accumulation of salts in the root zone. The water supply must be adequate generally to preclude shortages during the growing season and to permit additional off-season flooding where precipitation is insufficient to leach the seed bed. Cool, humid climatic conditions favor the use of more saline water than otherwise permissible, but use of any supplies containing more than 30 e.p.m. is highly questionable with few exceptions 10/.

Saline-Alkaline Water

B. Saline-alkaline waters are those which have concentrations of soluble sodium salts exceeding 20 e.p.m. but the salt combinations and soils are such that sodium is a limiting factor. The use of such water requires not only the conditions necessary for use of saline water, but the additional assurance that the soils will not develop high alkalinity, or develop restricted permeability to water. It is generally advisable to eliminate consideration of use of water supplies of such character unless: (1) the soils have demonstrated permanent, good permeability under continuous use of the water; (2) the water supply is plentiful; and (3) salt- and alkali-tolerant crops are grown. Coarse-textured soils, such as sandy loams and loamy sands generally permit use of waters approaching the saline-alkaline limits. However, laboratory and/or field tests are required to confirm the suitability of the water for use even on these soils. Past experience has demonstrated that even coarse-textured soils may occasionally "puddle," that is, become practically impermeable to water flow following prolonged use of such water as a result of breakdown of soil structure. It must be realized also that if a future change in the water supply results in the use of relatively pure water, sodium saturation and sealing of the soils may occur. Reclamation of such lands, if possible at all, has proved expensive and time consuming.

Alkaline Water

C. Alkaline water has a high sodium adsorption ratio but is relatively low in total dissolved solids. The controlling factor is the nature of the soils. Generally, soil sealing and development of poor drainage will eventually occur unless the soils are coarse-textured. As with saline-alkaline water, it is necessary to perform actual trials using water of the quality anticipated to determine the suitability of the supply for continuous use. Chemical amendments, such as gypsum, added to the water or soil may permit sustained use under careful management.

Boron Water

D. Water supplies with or without the foregoing conditions of salinity and alkalinity may contain limiting or excess amounts of boron as well. Crop tolerance is a very important consideration, particularly when intensive fruit cropping is anticipated. The coarse-textured soils are less desirable in this case, unless a better water supply can be assured for leaching the boron. Cool, humid weather permits the use of water containing the higher boron concentrations.

Turbid Water

E. The use of turbid water, or that which is or can be expected to be transporting a considerable sediment load directly to the land, may have beneficial or harmful results, depending upon the character of the project soils and nature of the sediment. Coarse, sandy soils may be more or less improved with respect to waterholding capacity and fertility by sufficient increments of finer materials. Conversely, fine-textured soils may be rendered less permeable by the addition of fine sediments. In many cases, the sediment is derived from eroded areas, and is of such poor quality that its accumulation on productive soils may reduce their fertility. In addition, turbidity is of some advantage in keeping down algae and various water weeds.

PRESENTATION OF RESULTS

.14 A complete discussion, data, and graphs relating to the chemical characteristics of particular flows, and of the anticipated or existing storage waters or other irrigation water supply should be included in planning reports as directed in

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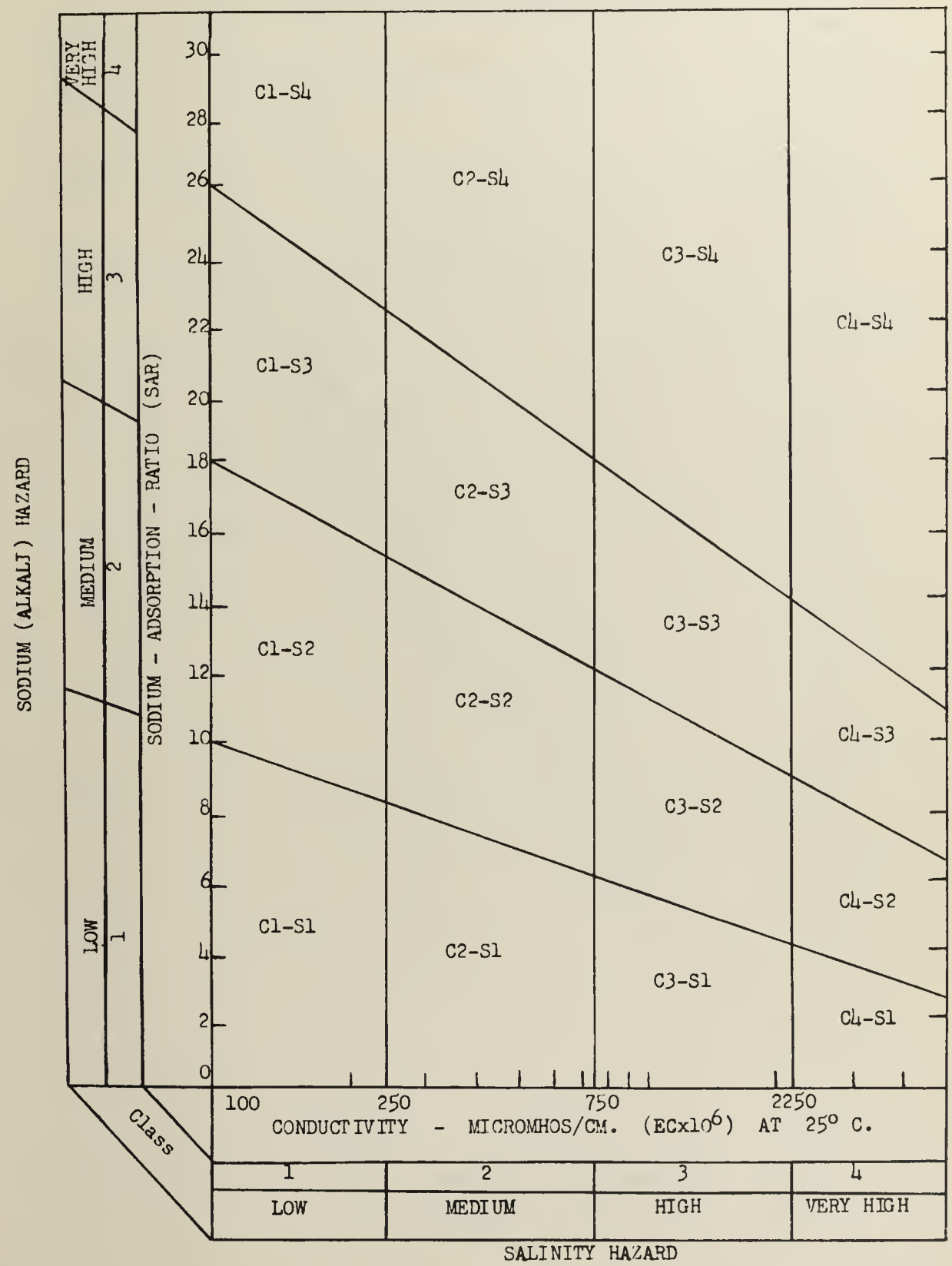
10/ "Irrigation Waters of Utah," Utah Agr. Exp. Sta. Bul. 346. June 1951.

PRESENTATION OF RESULTS (Cont.)

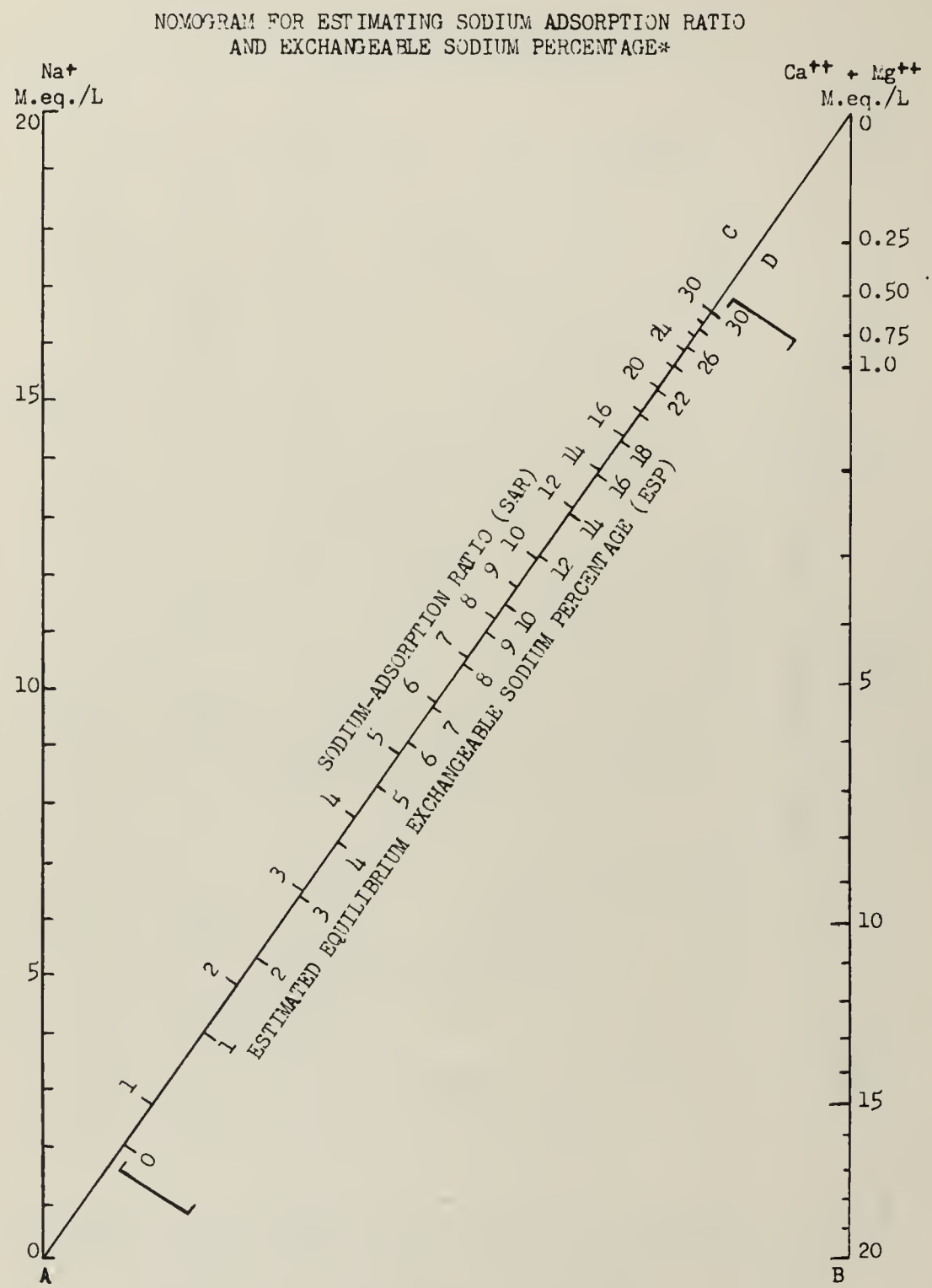
Chapter 4.2 of Volume III. Special problems related to irrigation use should be discussed in more detail in the Chapter on Project Lands and drainage problems related to quality of water should be discussed under Drainage in the planning reports (see Chapter 4.2 of Volume III). Reports on quality of water investigations on existing projects should also be prepared as needed in accordance with general instructions in Chapters 4.5 and 4.7 of Volume III.

DIAGRAM FOR USE IN INTERPRETING THE ANALYSIS OF IRRIGATION WATER*



*Source: "The Diagnosis and Improvement of Saline and Alkali Soils." U.S. Dept. Agr. Handbook (in process), 1953.

NOMOGRAM FOR ESTIMATING SODIUM ADSORPTION RATIO
AND EXCHANGEABLE SODIUM PERCENTAGE



* Source: "The Diagnosis and Improvement of Saline and Alkali Soils." U.S. Dept. Agr. Handbook (in process), 1953.

WATER SAMPLES

Project 161--Gen. Rec.--Kansas Stream Saline River Year 1941

Location Kansas (State) Russell (County) Wilson (near (Town))

Station identification Saline River gaging station near Wilson, Kansas
(Note specific location, such as highway bridge, U. S. Highway No. 24, etc.)
(Samples taken by Claussen)

Sample No.	Date	Hour	Gage Height	Tentative Discharge	River Stage	Remarks
1	1-4-41	2:15 PM	2.58	15		Some thin ice on edges Samples taken 2' from N.Bank
2	2-8-41	2:30 PM	2.60	16		Some thin ice
3	3-14-41	2:25 PM	2.64	20		
4	4-7-41	2:00 PM	2.78	34		
5	4-8-41	11:50 AM	4.98	530		First rise in spring
6	4-25-41	2:05 PM	2.85	42		

(See instructions on Sheet 2)

WATER SAMPLES (Continued)

INSTRUCTIONS

Procedure

In collecting sample select a section in the stream representative of the discharge and fill one bottle, which constitutes one sample. Samples are collected at regular intervals, daily, weekly, bimonthly, or monthly, during periods of uniform flow, and at intervals corresponding to the various stages of the river during flood flows. After six or twelve samples are collected from the various stations, ship to Denver via express in the cases provided. Refrain from allowing samples to stand for long periods; that is, 3 or 4 months before shipment. Exercise precaution against any possible contamination of the sample.

Sample No.

This should be permanently indicated on the sample-container to agree with a written record.

Date and Hour

These should include the month, the day, and the time of sampling.

Gage Height

If sample is taken at a gaging station, the outside staff gage reading should be recorded.

Discharge

With gage height recorded, discharge data should be secured from rating table in project office when available. When sample is taken at point other than at gaging station, discharge should be estimated and so noted in the remarks.

River Stage

This should be noted as rising, crest, falling, or low water, and should be indicated in addition to the staff gage reading.

Remarks

Here should be included any estimates of the river discharge and the time any flood rise begins, prior to the time of sampling, as well as any other data which might have a bearing on the representative quality of the sample. If samples are of ground water, the height of water level should be recorded.

REPORT OF WATER ANALYSES

Rel.49 5/25/53
Supersedes 11/7/50

7-1475
4-53
Bureau of Reclamation

REPORT OF WATER ANALYSES
Design and Construction Division
Engineering Laboratories Branch--Chemical Laboratory

Sheet 1 of 1

Date May 6, 1953

Date shipped April 2, 1953 By Acting District Manager, San Joaquin Valley District, Fresno, California

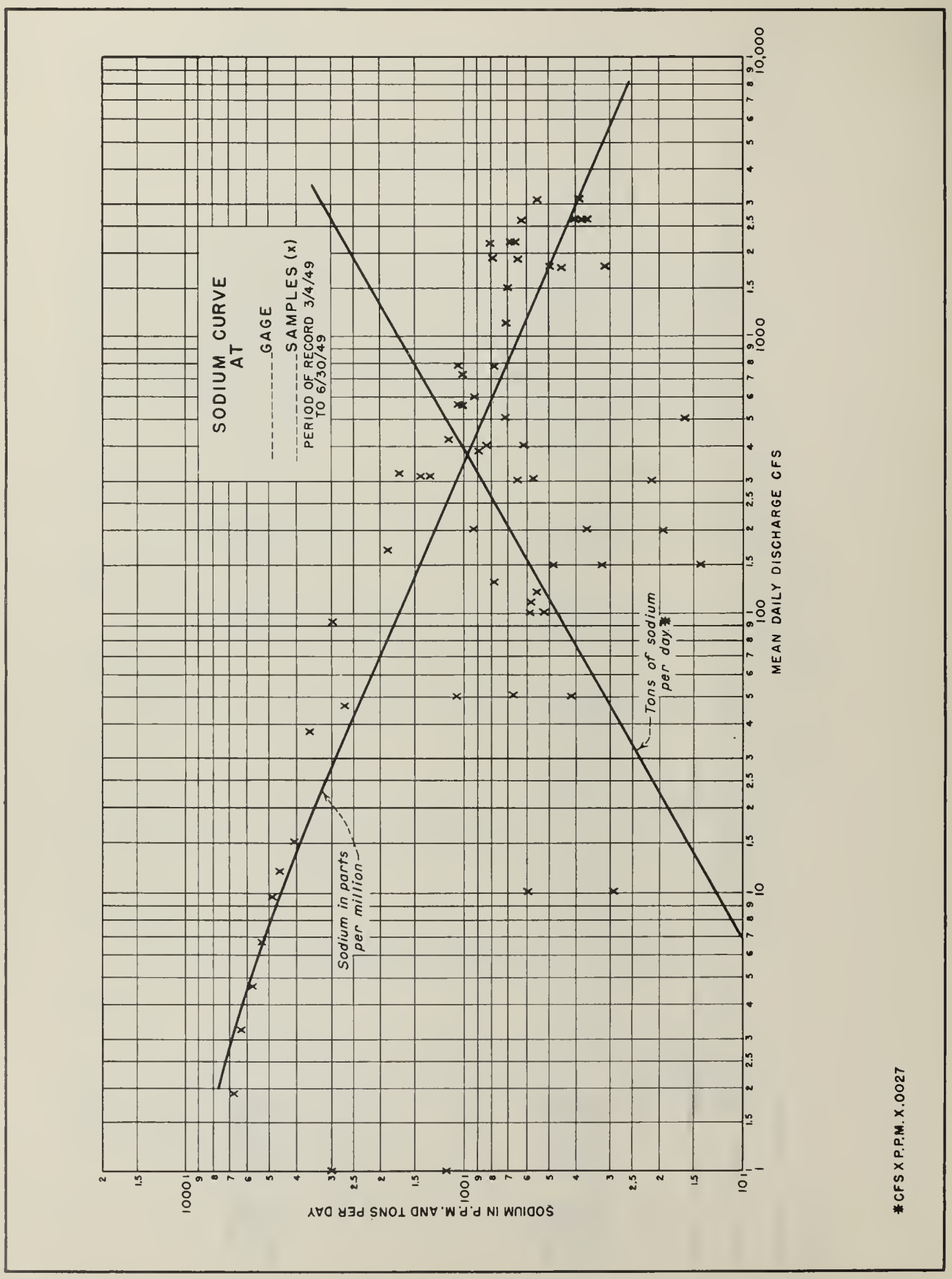
Date rec'd April 10, 1953 Analyst JSB-FG

Lab No	Field identification		K x 10^6 at 25° C	pH	% Na	Parts per million										
						TDS	B	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3
A-2605	12-12-12	1-F-3	36,541		90.5	34,826		430	324	10,534	9.0	0.0	104	18,048	4,544	226
A-2606	12-12-24A	1-C-3	1,395		54.4	950		86	26	182	9.0	0.0	253	317	135	1.2
A-2607	12-13-16A	2-F-1	5,010		49.9	4,628		373	163	736	3.9	0.0	115	2,798	121	12

			Milligram equivalents per liter								
A-2605	12-12-12	1-F-3	21.5	26.6	458	0.23	0.00	1.71	376	128	3.64
A-2606	12-12-24A	1-C-3	4.28	2.12	7.90	0.23	0.00	4.15	6.60	3.80	0.02
A-2607	12-13-16A	2-F-1	18.6	13.4	32.0	0.10	0.00	1.89	58.3	3.42	0.20
	To convert me/l to ppm, multiply by		20.0	12.2	23.0	39.1	30.0	61.0	48.0	35.5	62.0

Interior - Reclamation - Denver, Colo.

SODIUM CURVE



STREAM CONCENTRATION

STREAM CONCENTRATION
Tons per Month
April 1949

Day	Mean Daily Discharge	Tons of Ions				
		Na	Mg	Ca	K	T.D.S.
1	845	160	18.0	53.2	11.0	1060
2	680	139	16.2	45.2	8.7	950
3	595	128	15.0	41.0	7.7	880
4	560	125	14.4	39.0	7.3	800
5	610	130	15.2	41.8	7.9	880
6	708	140	16.4	46.8	9.2	960
7	818	152	17.9	52.3	10.6	1040
8	790	150	17.5	51.0	10.3	1030
9	708	140	16.4	46.8	9.2	960
10	550	120	14.3	38.5	7.2	790
11	459	110	12.9	33.6	6.0	720
12	374	94	11.5	28.9	4.9	600
13	305	81	10.3	24.5	4.0	560
14	288	79	10.0	23.7	3.8	500
15	322	89	10.6	25.8	4.2	570
16	311	88	10.5	25.0	4.0	560
17	204	66	8.4	18.1	2.7	440
18	132	50	6.6	13.0	1.8	328
19	102	47	5.7	10.4	1.4	272
20	85	42	5.2	9.0	1.2	236
21	75	39	4.8	8.0	1.1	215
22	67	36	4.5	7.2	1.0	196
23	56	33	4.2	6.2	.9	172
24	50	31	3.8	5.5	.8	158
25	44	29	3.6	5.0	.7	144
26	41	28	3.4	4.8	.6	136
27	37	26	3.2	4.1	.6	126
28	33	25	3.0	4.0	.5	116
29	31	24	3.0	3.8	.5	108
30	26	21	2.6	3.0	.4	96
31						
Total Per Mo	9906 cfs	2422	289.1	719.2	130.2	15603
Total A.F.	19812					

	Monthly Inflow Thous.A.F.		ration of Ions ervoir at end h in tons/A.F.			Concentration of Ions in Reservoir at end of Month in E.P.M.'s				Total E.P.M.'s	Sodium Adsorp. Ratio	
		C	Mg	Na	K	Ca(36.765)	Mg(60.270)	Na(31.969)	K(18.805)			
Col. No.	1		32	33	34	35	36	37	38	39	40	
Sept.('28)												Sept.('28)
Oct.	1.3		014	.130	.007	1.250	.844	4.156	.132	6.382	4.0	Oct.
Nov.	1.0		015	.134	.007	1.250	.904	4.284	.132	6.570	4.0	Nov.
W Dec.	0		015	.134	.007	1.250	.902	4.284	.132	6.570	4.0	Dec.
A T Jan.	0		015	.135	.007	1.250	.904	4.316	.132	6.602	4.1	Jan.
E R Feb.	0		015	.134	.007	1.250	.904	4.284	.132	6.570	4.1	Feb.
Y Mar.	48.9	1,3	013	.119	.007	1.176	.784	3,804	.132	5.896	3.8	Mar.
E A Apr.	6.5	2	013	.122	.007	1.213	.784	3.900	.132	6.029	3.8	Apr.
R May	3.9	1	014	.127	.007	1.250	.844	4.025	.132	6.251	3.9	May
1 9 June	14.4	4	014	.124	.007	1.250	.844	3.930	.132	6.156	3.8	June
2 9 July	.4		015	.129	.007	1.287	.904	4.089	.132	6.412	3.8	July
Aug.	0		015	.132	.007	1.323	.904	4.184	.132	6.543	3.9	Aug.
Sept.	0		016	.134	.007	1.360	.964	4.247	.132	6.603	3.9	Sept.
Total	76.4	2,4										

Derivation:

Col. 1
" 2,3,4,5
" 6
" 7
" 8
" 9,10,11,12
" 13,14,15,16
" 17,18,19,20
" 21

-F to E.P.M.

$$\frac{1}{136 \times 20} = 36.765$$

$$\frac{1}{136 \times 12.2} = 60.270$$

Col. 39 = sum of Cols. 35,36,37,38
Col. 40 = From Illustration 2 using Cols. 35, 36, 37.

$$Na = \frac{1}{.00136 \times 23} = 31.969$$

$$K = \frac{1}{.00136 \times 39.1} = 18.805$$

Table _____

RESERVOIR OPERATION TABLE--QUALITY OF WATER

	Monthly Inflow Thous.A.F.	Monthly Inflow Tons of Ions of: Ca	Mg	Na	K	Spills Thous.A.F.	% of Inflow Spilled	% of Inflow Retained in Reservoir	Tons of Ions Spilled (50%) at Inflow Concentration Ca	Mg	Na	K	Tons of Ions Spilled (50%) at Reservoir Concentration Ca	Mg	Na	K	Tons of Inflow Retained in Reservoir Ca	Mg	Na	K	Total Release from Reservoir Thous.A.F.
Col. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Sept.('28)																					
Oct.	1.3	70	60	480	10	0	0	100	0	0	0	0	0	0	0	0	70	60	480	10	.8
Nov.	1.0	55	53	400	8	0	0	100	0	0	0	0	0	0	0	0	55	53	400	8	.4
W Dec.	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	.4
A T Jan.	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	.4
E R Feb.	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	.4
Y Mar.	48.9	1,350	435	3,820	315	47.0	96	4	648	209	1,834	151	799	352	3,149	164	-97	-126	-1,163	0	.4
E A Apr.	6.5	275	137	1,150	44	5.3	82	18	113	56	472	18	85	34	315	19	77	47	363	7	.4
R May	3.9	180	108	850	28	1.4	36	64	32	19	153	5	23	9	85	5	125	80	612	18	1.5
1 9 June	14.4	498	200	1,120	95	11.6	81	19	202	81	454	38	197	81	737	41	99	38	-71	16	1.7
2 9 July	.4	20	35	220	4	0	0	100	0	0	0	0	0	0	0	0	20	35	220	4	4.3
Aug.	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	5.2
Sept.	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	4.6
Total	76.4	2,448	1,028	8,040	504	65.3			995	365	2,913	212	1,104	476	4,286	229	349	187	841	63	

	Tons of Ions Released from Reservoir Ca	Mg	Na	K	Tons of Ions Remaining in Reservoir Ca	Mg	Na	K	Reservoir Content End of Month Thous.A.F.	Concentration of Ions in Reservoir at end of month in tons/A.F. Ca	Mg	Na	K	Concentration of Ions in Reservoir at end of Month in E.P.M.'s Ca(36.765)	Mg(60.270)	Na(31.969)	K(18.805)	Total E.P.M.'s	Sodium Adsorp. Ratio	
Col. No.	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	
Sept.('28)																				Sept.('28)
Oct.	26	11	101	6	3,021	1,272	11,719	597	89.6	.034	.014	.130	.007	1.250	.844	4.156	.132	6.382	4.0	Oct.
Nov.	14	6	52	3	3,062	1,319	12,067	602	89.8	.034	.015	.134	.007	1.250	.904	4.284	.132	6.570	4.0	Nov.
W Dec.	14	6	54	3	3,048	1,313	12,013	599	89.3	.034	.015	.134	.007	1.250	.902	4.284	.132	6.570	4.0	Dec.
A T Jan.	14	6	54	3	3,034	1,307	11,959	596	88.9	.034	.015	.135	.007	1.250	.904	4.316	.132	6.602	4.1	Jan.
E R Feb.	14	6	54	3	3,020	1,301	11,905	593	88.5	.034	.015	.134	.007	1.250	.904	4.284	.132	6.570	4.1	Feb.
Y Mar.	14	6	54	3	2,909	1,169	10,688	590	90.0	.032	.013	.119	.007	1.176	.784	3,804	.132	5.896	3.8	Mar.
E A Apr.	13	5	48	3	2,973	1,211	11,003	594	90.0	.033	.013	.122	.007	1.213	.784	3.900	.132	6.029	3.8	Apr.
R May	50	20	183	10	3,048	1,271	11,432	602	90.0	.034	.014	.127	.007	1.250	.844	4.025	.132	6.251	3.9	May
1 9 June	58	24	216	12	3,089	1,285	11,145	606	90.0	.034	.014	.124	.007	1.250	.844	3.930	.132	6.156	3.8	June
2 9 July	146	60	533	30	2,963	1,260	10,832	580	84.2	.035	.015	.129	.007	1.287	.904	4.089	.132	6.412	3.8	July
Aug.	182	78	671	36	2,781	1,182	10,161	544	77.2	.036	.015	.132	.007	1.323	.904	4.184	.132	6.543	3.9	Aug.
Sept.	166	69	607	32	2,615	1,113	9,554	512	71.4	.037	.016	.134	.007	1.360	.964	4.247	.132	6.603	3.9	Sept.
Total	711	297	2,627	144																

Derivation:

Col. 1 = regular monthly inflows from Reservoir Operation chart
" 2,3,4,5 = from curves - Monthly Inflow vs. Tons of Ions
" 6 = from Reservoir Operations
" 7 = Col. 6 divided by Col. 1
" 8 = 100% minus Col. 7
" 9,10,11,12 = 50% of Col. 7 times Cols. 2,3,4,5
" 13,14,15,16 = 50% of Col. 6 times Cols. 31,32,33,34 (Use previous month concentrations)
" 17,18,19,20 = Cols. 2,3,4,5 minus Cols. 9,10,11,12 minus Cols. 13,14,15,16
" 21 = from Reservoir Operation

Cols. 22,23,24,25 = Col. 21 times Cols. 31,32,33,34 (for previous month). Concentration of total releases for the current month is based upon the reservoir concentrations at end of previous month.
" 26,27,28,29 = previous month (Cols. 26,27,28,29) plus net inflow (Cols. 17,18,19,20) minus release (Cols. 22,23,24,25)
" 30 = from Reservoir Operation
" 31,32,33,34 = Cols. 26,27,28,29 divided by Col. 30

Cols. 35,36,37,38 are Cols. 31,32,33,34 changed from A-F to E.P.M. with following constants:

Tons per A.F. = PPM x .00136

$$PPM = \frac{\text{Tons per A.F.}}{.00136}$$

$$E.P.M. = \frac{PPM}{\text{Equiv.Wt.}} = \frac{\text{Tons per A.F.}}{.0036 \times \text{Equiv.Wt.}}$$

$$Ca = \frac{1}{.00136 \times 20} = 36.765$$

$$Mg = \frac{1}{.00136 \times 12.2} = 60.270$$

$$Na = \frac{1}{.00136 \times 23} = 31.969$$

$$K = \frac{1}{.00136 \times 39.1} = 18.805$$

Col. 39 = sum of Cols. 35,36,37,38
Col. 40 = From Illustration 2 using Cols. 35, 36, 37.

Table ____

.1 The two basic factors in irrigation developments, land and water resources, are interrelated by the determination of water requirements for irrigation. If land is the limiting factor, the unit water requirement determines the depletion of the water supply available for basin use; if water is the limiting factor, the unit water requirement determines the size of a project area which can be irrigated. Special conditions will dictate whether the project area will receive a full water supply, a reasonably adequate supply, or some degree of supplemented supply, but the water requirement for a full supply is the measure of adequacy. BASIC FACTORS

.2 Earlier irrigationists used the term "duty of water" instead of "water requirement" usually without specifying exactly whether the reference was to diversion or to delivery. The term originally implied efficiency of use; hence, a high duty actually meant a small use; a low duty, a large or wasteful use. Later, the term was applied to mean amount of use; and, at present, the usage of the term is very loose. To avoid confusion, reference to amount of water needed per acre should be stated specifically with terms such as "diversion requirement," "farm delivery requirement," or "crop irrigation requirement" when speaking of demands on streamflow, whether or not regulated by storage. In referring to crop moisture requirements, "consumptive use" is permissible instead of "consumptive use requirement" as this term has been clearly defined in engineering literature (see also Subparagraph 4.1.7B). DEFINITION

.3 While it is desirable to extend project water supply studies over as long a period as possible, water requirements should be set sufficiently high that the project can be operated through a critical drought period without failure. Water requirements during years of above-normal temperature are usually higher than in normal years and rainfall during such periods is usually subnormal. Studies to determine project water requirements for irrigation should, therefore, consider the need during a period of about 10 consecutive years, including the worst drought period of record in the Region, with reference to longer periods if records are available. CRITICAL PERIOD OF STUDY

.4 The best source of data on water requirements on a project area is the experience of good irrigators within the project or in adjacent similar areas, who have access to an adequate water supply and who have determined after years of careful experimentation the proper amount of water to apply to their lands under the type of agriculture adapted to local conditions. Many irrigators use water improperly through lack of understanding or because their available supplies are inadequate in amount or improperly distributed. Irrigators with abundant water commonly apply more than is desirable, either because they have it to use and fear that they may lose the right to use it regardless of whether they are actually putting it to the best use or because they cannot justify the expense of land preparation and labor for full coverage with lesser amounts. Overuse in the early months of the irrigation season is characteristic where there is little or no surface storage and irrigators are attempting to store water in the soil against uncertain late season supplies. This situation is, of course, worse in the case of junior right users than those holding early rights. The situation is frequently so severe that no users have a sufficient amount to mature late season crops and are necessarily restricted to lower income crops than would be possible with a full water supply. LOCAL PRACTICE

.5 If successful farmers, with reliable water supplies adequate to produce crops comparable in type and yield to those anticipated with a full project water supply, can be found, an effort should be made to obtain data on their use. Their cooperation can usually be gained and arrangements can be made to secure measurements of irrigation deliveries and rainfall. Such measurements give the delivery requirement with full allowances for climate, character of soil, crops, and agricultural practice. The equipment for making the measurement will usually be a sharp-crested weir or Parshall flume, at the head of the farm ditch or field turnouts, controlled by frequent observations or by an automatic recorder. Rainfall can be measured in a standard Weather Bureau rain gage. LOCAL COOPERATION

EXPERIMENT STATION RECORDS

.6 Experiment station records on irrigation use may sometimes be used in estimating farm delivery requirements, especially in establishing monthly distributions. Station experiments are performed for many purposes for comparing varieties, fertilizers, and practices, and for this reason may not suitably represent average farm practice in the project area. In cases where treatment is normal, however, sometimes valuable information may be obtained if it is anticipated that one or two crops will predominate. In such cases, it may be possible to weigh requirements for the individual crops and so arrive at a more suitable figure than for a normal distribution of crops, especially as to the seasonal distribution of transpiration demands. In many new areas, the Bureau of Reclamation is developing demonstration farms. Data obtained from such farms may prove most useful as there will ordinarily be no other records of farm irrigation use on completely new projects.

CONSUMPTIVE USE METHOD

.7 If there are no reliable and representative local data on farm delivery requirements of irrigation water, it is necessary to estimate the requirement for the project under study. For this purpose the Lowry-Johnson consumptive use method 1/ developed by the Bureau of Reclamation is recommended for general use, although some modification may be found necessary in areas of high humidity, excessive wind velocities, or excessive rainfall. Most of the irrigated areas used in establishing the method are in and near the Rocky Mountains where humidities are generally low. The method is also useful, where there are adequate data on farm delivery requirements, in estimating return flow. ★The Lowry-Johnson curve does not extend high enough to provide an estimate of the consumptive use in areas where the growing season is 11 or 12 months long and the average temperatures are high. It is not considered advisable to attempt to extend the curve, unless additional results can be obtained. The method is applicable to areas where diversified general crops are grown, but is of doubtful value in areas devoted primarily to specialty crops such as citrus fruits, dates, nuts, avocados, etc., or where a single crop having water requirements far from the average is grown.★

Basis of Lowry-Johnson Method

A. The Lowry-Johnson method is an empirical one employing the relation of growing season effective heat to annual consumptive use of water. The relationship was established by reference to a considerable number of irrigated valleys or areas for which records of inflow and outflow were available or could be estimated closely, and where water supplies are adequate for the production of the usual crops grown on most irrigation projects under comparable climatic conditions. The results are general and should be modified for conditions of climate or crop distribution appreciably different from the areas used in establishing the curve.

Consumptive Use Defined

B. Consumptive use as defined for the method is the quantity of water per year, in acre-feet per acre of area equivalent in use to cropped land, absorbed by the crop and transpired or used directly in the building of plant tissue together with that evaporated from the area. It includes water originating in precipitation on the land from the atmosphere as well as that diverted from streams or entering the area as underground flow available for transpiration or evaporation within the area.

Procedure

C. By deducting the amount of rainfall to be consumed on the area, it is possible to estimate the crop irrigation requirement. To this is added an allowance for estimated deep percolation losses and waste in application to obtain the estimated farm delivery requirement. A further addition for estimated conveyance loss and waste between source of supply and the farm gives the diversion requirement.

1/ "Consumptive Use of Water for Agriculture" by Robert L. Lowry, Jr., and Arthur F. Johnson. Paper No. 2158, p. 1243, Vol. 107, Transactions of the American Society of Civil Engineers, (1942).

.8 Effective heat, as defined for the method, is the accumulated maximum daily temperatures in degrees Fahrenheit above a base of 32° F during the effective growing season. The effective growing season used for the method does not coincide directly with the period between latest killing frost in the spring and earliest killing frost in the fall as given by the Weather Bureau, but upon the date a smoothed curve of minimum temperature at last rises above a base of 32° F in the spring and remains above it until it again drops below that base in the fall. Minimum temperatures are smoothed by applying the following formula: EFFECTIVE HEAT

$$\frac{a + 2b + 3c + 4d + 5e + 4f + 3g + 2h + i}{25}$$

The letters indicate minimum temperatures on consecutive days. The simplest determination of the smoothed minimum temperatures by the formula is to calculate 5-day moving totals of minimum temperatures and then repeat the process with 5-day moving totals of the first totals, divide the final values by 25 and offset the smoothed mean back 4 days to the middle of the 9-day group used in the computation. Except in those cases when minimum temperatures fluctuate above and below 32° F at the beginning and end of the season, it is usually satisfactory to fix the limits of the growing season by inspection of minimum temperature records.

.9 The distribution of first-order and cooperative Weather Bureau stations is in nearly all cases sufficient to afford ready reference temperature records to compute effective heat for the Lowry-Johnson consumptive use method. The Weather Bureau publishes numerous temperature records in "Climatological Data" but many unpublished records are available in the central offices of the Weather Bureau and can be obtained by securing copies of the original observers' reports. For compact project areas of less than 20,000 acres, one representative station is adequate; but if the project area is extended with considerable differences in elevation at its extremes, it is desirable to use a station near each end. For larger project areas, the number of stations should be increased but the ratio of acres per station may be increased considerably. Few projects should require use of more than five or six stations for determining average consumptive use. If the differences in effective heat in different parts of the project are so wide as to give concern over the difference in consumptive use, the project should be broken into divisions and the effective heat and water requirements for each division should be computed separately. SELECTION OF TEMPERATURE RECORDS

A. Where project areas are unevenly distributed with respect to the available stations, it will be desirable to weight the effective heats according to area, either arbitrarily, by natural breaks in the area, or by a graphical method, such as the Thiessen polygon method employing perpendicular bisectors of lines drawn between stations on the map, to define the areas nearest each station. Where stations are at some distance from an area, the weighting may be made according to the relative distances from area to station. Weighting Records

B. In occasional instances it may be necessary to use a temperature record for a station of considerably different elevation from the project area. It will then be necessary to estimate the effective heat and length of growing season. Correlation of temperatures against elevations for stations in the Region will be useful for such estimates. The usual average decrease in temperature with increase in elevation is between 3.5° F and 4° F per 1,000 feet but local conditions such as exposure to winds or proximity to mountains may affect the relationship. Estimates

.10 The average effective heat derived for the project or for each selected subdivision is referred to the effective heat-consumptive use curve, to obtain the annual consumptive use. For rough studies on projects to be supplied entirely from storage, an annual estimate is adequate but for most studies a MONTHLY CONSUMPTIVE USE

MONTHLY CONSUMPTIVE USE (Cont.)

monthly distribution of consumptive use is needed in order to carry out operation studies. There are few reliable data on monthly distribution of consumptive use on large projects because of the changing condition of ground-water storage during the growing season. Data secured during consumptive use studies for the Mason Creek area of the Boise Project, Idaho, in 1917, and for the Mesilla Valley, Rio Grande Project, New Mexico, are tabulated below:

Month	Mason Creek Area Boise Project Feet	Mason Creek Area Boise Project Percent	Mesilla Valley Rio Grande Project Feet	Mesilla Valley Rio Grande Project Percent
January	.03	1.4	.03	1.1
February	.04	1.8	.07	2.5
March	.07	3.2	.15	5.4
April	.15	6.8	.24	8.6
May	.26	11.8	.26	9.3
June	.36	16.3	.37	13.2
July	.38	17.3	.51	18.3
August	.37	16.8	.49	17.6
September	.25	11.4	.33	11.8
October	.13	5.9	.18	6.4
November	.09	4.1	.10	3.6
December	.07	3.2	.06	2.2
Total	2.20	100.0	2.79	100.0

The growing season for the Mason Creek area was from April 7 to October 4, and the average growing season for the Mesilla Valley from March 16 to November 10. The Mason Creek area was largely in alfalfa; the Mesilla Valley largely in cotton. The distribution of consumptive use for Mesilla Valley reflects the break in consumptive use during the planting season in May which would not be so evident with a larger percentage of perennial crops.

Effect of Soil Reservoir

A. There should be little difficulty with any estimate of monthly consumptive use based on the above data as the soil is a moisture reservoir and will ordinarily equalize drafts on moisture supply over a range of several inches. Plants have the ability to extract needed moisture through a wide range of soil moisture contents from the wilting point to the field moisture capacity with little change in efficiency. Winter consumptive use, except in the warmer areas where perennial crops remain green and double cropping of annuals is possible, is primarily evaporation from the exposed soil or snow surface. It will vary from season to season depending upon the available moisture supply near the surface. In areas of low winter precipitation there may be some drying of the soil but it is unnecessary to replenish it until the beginning of the growing season unless a winter crop is growing.

SELECTION OF PRECIPITATION STATIONS .11 The choice of precipitation station records follows the same general principles stated for choice of temperature station records. Data are usually available for more precipitation stations than temperature stations. The records used should be representative of conditions over the watershed. If the precipitation range is great, it is desirable to break the projects into divisions or units to reflect this difference.

EFFECTIVE PRECIPITATION .12 Only a part of the precipitation falling on a project area is effective in meeting consumptive use requirements. The effectiveness of the precipitation depends upon several factors such as amount and intensity, character of soil surface, storage capacity, and the rate of consumptive use. Practical judgment is necessary in all cases as the accuracy of basic data does not warrant great refinement in study.

In Winter

A. In winter, in areas of low winter precipitation, the total is frequently effective as the soil is usually able to absorb it all. However, where a considerable part falls in a few storms as snow on frozen ground, rapid melting may produce some runoff. Values of 90 to 100 percent effectiveness should ordinarily be applied. In areas of high winter precipitation,

consumptive uses are supplied in full and a large part of the excess may run off, especially if snowmelt is involved. Where most of the precipitation falls as rain on unfrozen ground, the soil may become fully saturated with the excess, down to field moisture capacity (the amount the soil will hold by capillary attraction against the pull of gravity), being lost by deep percolation or surface runoff. It is permissible under these conditions to adjust irrigation applications so that the moisture supply in the soil reservoir is drawn down in the fall at the beginning of the rainy season in order that a maximum amount of winter precipitation can be captured and held over into the growing season. The capacity of soil for absorbing and holding water varies with its depth and structural characteristics. The porosity of a sandy soil may run as low as 20 percent while that of clay soils may exceed 50 percent, but other factors also influence moisture-holding capacities. The pore spaces in coarse sandy soils are relatively large and most of the storage space can be filled readily, but, capillarity porosity is low in such soils and a large part of the water drains freely from the soil under the force of gravity. Finer sandy loam and loam soils normally have both greater pore space and holding capacity than sandy soils. Heavy clay soils, especially where there is a high colloid content, have a large percentage of pore space, but movement through the small pore is slow and the space commonly does not fill completely because of the presence of trapped air; hence, the field capacity is low. When moisture supplies are used by plants or by evaporation, a part of the moisture is held by the increasing surface tension in films about the individual soil particles. The capacity of the soil for retaining available moisture is the difference between the field capacity and the point at which permanent wilting occurs. The normal range will lie between a minimum moisture content slightly above the wilting point and the field moisture capacity. ★ Since available moisture capacity represents a range which varies with depth, texture, structure, and composition of the soil, it is not practical to establish general limits which are applicable to all areas. The available moisture capacities of representative soils are measured as a part of the land classification investigations and these data should be consulted by the hydrologist (see Chapter 2.10 of Volume V). ★ The effective depth of the soil with respect to the depth of root penetration and the percentage of roots at different depths differs with different crops and with their stage of growth. For present purposes it may be considered to average about 3 to 4 feet although for alfalfa a greater average depth applies.

In Winter (Cont.)

B. In arid areas where precipitation is undependable, usually in light showers or very short thunderstorm-type rains, evaporation losses are high. Showers of less than 1/4 inch are commonly evaporated, regardless of the number per month, with little benefit to the growing crop other than cooling of the atmosphere. However, inasmuch as consumptive use values by the Lowry-Johnson method were determined by inflow-outflow measurements, average evaporation from all rains, including showers of less than 1/4 inch, have been included as a part of the consumptive use. For these areas it is customary to compute the average precipitation during the dryer years, such as a critical 10-year period, or even more conservatively for the 5 driest years of record without regard to succession; and to apply a coefficient of effectiveness ranging in value from 70 to 90 percent. This average effective precipitation is deducted from the consumptive use estimated by reference to heat units and the resulting crop irrigation demand is applied uniformly through the entire period of study without regard to rare storms or periods without rain. In the subhumid areas of the Great Plains, an appreciable moisture supply is realized from frequent soaking rains during the summer months. Rainfall may supply all crop requirements in some months, but be inadequate to supply requirements in succeeding months. Water requirement studies in semiarid or subhumid areas must consider precipitation as it occurs during the study period and evaluate its effectiveness on a monthly or even on a storm basis. Practice varies as to treatment but in most cases use of monthly records is satisfactory. Percentages of effectiveness are applied to increments of monthly rainfall ranging from over 90 percent effectiveness for the first inch to zero effectiveness for amounts in excess of 6 inches per month. The following ranges are suggested:

During Growing Season

During Growing Season (Cont.)

Precipitation Increment Inches	Effective Precipitation Percent	Effective Precipitation Inches Accumulated
1	90-100	.90-1.00
2	85- 95	1.75-1.95
3	75- 90	2.50-2.85
4	50- 80	3.00-3.65
5	30- 60	3.30-4.25
6	10- 40	3.40-4.65
over 6 inches	0- 10	3.40-4.75

CROP IRRIGATION REQUIREMENT .13 The estimated effective precipitation is deducted from the corresponding estimated consumptive use to obtain the crop irrigation requirement. For convenience, the nonirrigation season months are commonly lumped together and the irrigation season requirements divided by months. ★ In periods when effective precipitation exceeds the consumptive use, the excess can, under many conditions, be considered to accumulate from month to month so long as the accumulated carry-over does not exceed the estimated capacity of the soil profile (between the wilting point and the field capacity). This soil reservoir content can then be considered used during subsequent months when the consumptive use requirement exceeds the effective precipitation. (See Page 9 of Appendix I.) ★

EQUIVALENT AREA .14 Instead of referring to cropped area or to gross area as a basis for computing consumptive use, an estimate is frequently required of the area consuming water at a rate equivalent to that on the cropped area. In determinations of stream depletion or usable return flow, an estimate of consumptive use by nonbeneficially consuming areas is required but the use may be computed directly rather than in terms of equivalent irrigated areas if desired. Thus, allowance will be made for nonbeneficial consumptive uses in nonfarmed areas within the boundaries of the project or surrounding it, that will receive some irrigation water either through surface waste or through subirrigation from underground flow or capillary movement. High areas consuming only precipitation or consuming a negligible amount of irrigation water should be omitted. Corrections to the remaining area should be made to compensate for unbalanced conditions caused by swamp lands which will consume water at a higher rate than cultivated land and by natural vegetation adjacent to irrigated areas which will consume less water than the average for cultivated land. These corrections will be a matter of judgment. The net effect will usually be small, as the cropped land in most agricultural valleys amounts to about 85 percent, or more, of the gross area which may consume irrigation water. In some mountain valleys, however, where irrigation water is applied lavishly, seepage and waste is so abundant that they may supply large areas of waste land. Under these conditions cropped land may represent less than 50 percent of the water-consuming area. The hydrologist making the studies must be careful to distinguish between lands which will unavoidably consume water applied in order to permit irrigation of those lands that are part of the project, and lands which will receive their supply from waste, seepage, etc., which would otherwise become return flow. The lands that come under the former classification must be allowed for in computing the farm delivery and diversion requirements. Those under the latter will reduce the amount of return flow but have no bearing on the diversion requirements.

FARM DELIVERY REQUIREMENT .15 In practice it is infeasible to supply crop irrigation requirements without losses and waste. In applying water by surface methods, the soil at the upper end of the run receives more water than it can retain before that at the lower end of the run is served and the excess percolates below the root zone. Any excess, reaching the lower end of the run, drains off into waste ditches and drains, or onto waste land unless it can be diverted onto other irrigable land. Other wastes may occur as a result of the breaking of farm ditches. Under conditions of soil or water high in salt concentration, it is desirable to apply extra water to insure proper dilution of the soil moisture in the root zone and leaching of salts below the root zone to prevent accumulation to harmful proportions.

A. The losses due to deep percolation are dependent on the depth and character of the soil, the length of the run, the slope of the ground, and the rate of application. The seepage losses in sandy soils are greater than on heavier, tighter soils, but surface conditions may be offset by the character of the subsoil which may be heavier or lighter than the surface soil, or may contain tight zones consisting of lime accumulations or other hardpan. Some soils are underlain at shallow depth by shale or well-cemented sandstone resistant to percolation. In other cases where the water table is high and subsurface movement is restricted, the capacity of the soil reservoir is small. Usual deep percolation losses range from 15 to 50 percent of water applied, but under exceptional conditions, as with sprinkler irrigation, they may be less than 5 percent; and with wild and continuous flooding over 70 percent of the water applied. Surface farm wastes are ordinarily about 5 percent but may range from 0 to 20 percent or more depending upon care in application. For new projects, the design values for combined deep percolation losses and surface waste should range from about 20 percent to 60 percent of farm delivery, depending upon the character of the soil and the efficiency of the irrigation method used. Deep Percolation & Waste

B. Deep percolation losses in light-textured soils may be reduced by shortening the length of run, applying larger "heads" of water for shorter intervals, or increasing the number, and decreasing the depth of irrigation application. However, on tight soils, particularly on sloping ground, these practices may increase surface wastes and best economy is obtained by using small heads and long runs. Where the Bureau of Reclamation takes over the full operation of an irrigation project by acquiring existing rights, some saving in losses and waste, through improved practices, should be assumed. Such changes should be anticipated also where the addition of storage to insure a late season supply will change cropping practice to a higher value crop which will warrant better land preparation and more care in application of water. The border or check method of alfalfa irrigation, with application of 2 or 10 second-feet for periods of 30 minutes to 2 hours per acre, is usually more saving of water than use of a continuous flow at the usual rates of 1 second-foot per 50 to 70 acres on unleveled land by means of a few field ditches. Use of cross ditches at 200-foot intervals to serve furrows on sandy soil will prevent much deep percolation as compared with applying the same "head" of water in furrows a quarter of a mile in length. Sprinkling can be regulated to prevent deep percolation losses and surface waste entirely. Effect of Irrigation Practice

★C. Land classification data are particularly useful in estimating farm delivery requirements. In many areas it is generally possible for the hydrologist to group land classes and subclasses into farm requirement classes. The difficulties and exceptions may be such in areas of complex land conditions and critical water supply that informative appraisals of farm water delivery requirement will be desirable, as outlined in Chapter 2.7 of Volume V.★ Farm Delivery Requirements

.16 The term "leaching" refers to the action of water applied for the removal of deleterious salts from the soil either where they have accumulated prior to initiation of irrigation or where continued movement is necessary to maintain a desirable salt balance. Removal may be effected either by flushing away surface accumulations by flooding or by applying sufficient water to carry the salts down below the root zone. The origin of the salts may be in the subsoil as they are a component of some shales, or they may be transported to the area from external sources by inflowing water. The problem of water quality and its effects upon the soil are given general discussion in Chapter 2.4. LEACHING

A. In areas of high water table and restricted drainage where moisture is obtained by subirrigation, capillarity lifts the water to the surface and it is evaporated from the soil or transpired by growing plants. As the amount of salts absorbed by plants and utilized in the production of their tissues is relatively small, excess salts, dissolved in the rising waters, are deposited in the upper few inches of the soil, or on its surface. This surface accumulation of salts is best removed by flushing at a season when surplus waters Surface Accumulations of Salts

are available for that purpose--during the winter or in the spring flood season. The amount of water required for flushing is usually governed by the method of application rather than by the amount of salts to be dissolved. The water must move over the surface with sufficient rapidity that the salts are carried away rather than washed back into the soil.

Salts in Root Zone

B. A different problem exists in the case of better drained soils irrigated with waters containing high percentages of dissolved salts. In this case water is applied to the soil surface and as it moves downward, plant roots extract the water and concentrate the solution of salts in the root zone to a degree harmful to the plants. It is thus necessary to assure sufficient application of water to hold the root zone concentration to tolerable limits and to facilitate movement of the solution downward below the root zone and away from the area by natural or artificial drainage. Following is an equation for estimating approximately the minimum application or farm delivery requirement of irrigation water containing dissolved salts in order to insure against raising the soil solution concentration above a desired amount. The equation assumes no absorption of the salts by growing plants.

$$D_f = \frac{2\,C_r - C_a}{2\,C_r - 2\,C_a} D_c \quad \text{2/}$$

where

D_f = depth of application necessary to provide sufficient percolation through the root zone to keep the soil solution concentration below a desired limit, C_r

D_c = depth required for consumptive use in the same units as D_f (feet)

C_a = concentration of salts in the irrigation water applied in the same units as for C_r (conductance or parts per million)

C_r = the desired upper limit of concentration of salts in the soil solution at the root zone. This depends upon the character of salts and is best determined by a consideration of local conditions.

COMPUTED FARM DELIVERY REQUIREMENT

.17 The farm delivery requirement, R_f, is equal to the crop irrigation requirement, R_i, divided by the quantity $(1 - L_f)$, where L_f is the allowance for deep percolation and waste incident to application expressed as a decimal rather than as a percentage. As the conditions affecting seepage losses and waste remain essentially constant during the season, it is customary to increase all monthly amounts in the same ratio.

$$R_f = \frac{R_i}{1 - L_f}$$

where

R_f = farm delivery requirement (feet) ★per productive acre★

R_i = irrigation requirement (feet)

L_f = farm losses (deep percolation and waste) expressed as decimal ratio of farm losses (feet) to farm delivery (feet).

2/ Equation developed by Mr. Raymond A. Hill, Consulting Engineer of Los Angeles, California.

.18 Conveyance losses are those losses of water in transit from the source of supply to the point of service whether in natural channels or in artificial ones such as canals, ditches, and laterals. They comprise evaporation from the water surfaces, seepage, and incidental transpiration by water-loving vegetation growing in the water or along the banks of natural channels, canals, and laterals. Operational wastes are those losses due to lack of efficiency in management and breaks in the conduits. In estimating diversion requirements, all conveyance losses and waste are ordinarily lumped together into a single estimate. CONVEYANCE LOSS & WASTE

A. Evaporation from canals and laterals is ordinarily negligible in comparison with seepage losses. For example, 100 miles of canal, 40 feet wide, has a surface area of only 485 acres and maximum monthly evaporation would total only about 200 to 250 acre-feet on most Bureau projects; only a fraction of the total loss and waste for the month. Only in extraordinary circumstances is evaporation computed separately. Canal Evaporation

B. Vegetation, growing in or along canals, takes a small toll of water directly from the canal contents but in many cases the roots draw from seepage water. The principal detriment of vegetation along canal banks is in retarding flow rather than consumption of water and for this reason maintenance work will ordinarily hold transpiration uses to minor amounts. Transpiration Losses

C. Bank storage and channel storage of water may be factors to be considered in some situations. While these are not losses, they may affect the early flows in a manner similar to losses and may cause a shift in the distribution of the diversion demand. Bank storage is the seepage of water into the banks of the channel during the early periods of flow with later return to the channel as the water level is lowered. Only that portion of the total seepage that is actually returned can be considered as bank storage; the rest is a seepage loss. This storage factor will generally be ignored as the usable return will be negligible; but, in conveyance through natural channels, from one reservoir to another, especially if releases are made at intervals, it may be necessary to give it consideration as it may amount to a considerable item. Channel storage is the volume of water in the channel of a stream or canal. It is stored as the channel fills, and empties as the channel drains. Bank & Channel Storage

D. Seepage from canals ordinarily follows the laws of percolation through a porous medium. It varies directly with wetted area, head and permeability, and inversely with distance of travel through the soil. The latter may be ignored as the wetted area, depth,and permeability are the important items. Formulas for seepage based on these factors have been developed but they are not very practical because of the difficulty of evaluating the permeability coefficient which has a wide range depending upon the character of the soil and its current condition. Seepage Losses

E. Some states have statutes or operating rules providing a method of accounting for conveyance losses. These frequently require deduction of a flat percentage of the flow, or a percentage per mile. Such state requirements should be recognized. If they are not reasonable for the conditions anticipated, the local and state officials may be able to make changes that will provide a more equitable means of allowance for conveyance losses. If the studies do not conform strictly with such local or state regulations, the report should clearly state this fact. It should also explain why it departs from them and what should be done to provide a more reasonable and just allowance. Administrative Deductions for Losses

F. It is common practice to consider canal loss as a percentage of the discharge but it is apparent that the hydraulic properties of the canal and the method of operation may cause the percentage loss to vary greatly. Thus, reducing the discharge of the ordinary wide canal by 50 percent will result in only a minor reduction in wetted area and flow producing head; hence, losses throughout the season remain more or less uniform regardless of the amount of the diversion. In many canals, checking is practiced to maintain a uniform head on turnouts, regardless of total discharge. Priming losses are frequently of some significance as there is a tendency Percentage of Discharges

in canals to seep more heavily after disuse than when fully conditioned because of cracks produced by drying, loosening of the soil structure by frost action, etc. If canals are cleaned regularly each year, a certain amount of the tight silt layer is removed and seepage is increased until fresh silt deposits are built up.

OPERATION WASTE .19 Operation wastes include releases to wasteways resulting from refusal of users to accept water on delivery or in making rotations up the canal where check storage is involved; outflows through breaks in the canal, or overflows due to obstructions; and leakage past gates, and other structures, or through holes made by rodents. Operation wastes range widely depending upon the availability and cost of water, and upon the care exercised in delivering it through policing canals and laterals to prevent breaks and wasteful practices. On some systems where users are shareholders, diversion is on a continuous basis and water runs whether the owner uses it or not. He may irrigate only in daylight and shut down his turnouts on Sundays and holidays. In other systems water is rotated on a careful schedule and refusal to accept or to trade turns means loss of the water.

FIELD MEASUREMENT OF LOSSES & WASTE .20 The most reliable basis for estimating conveyance losses is a reference to losses on constructed canals of similar size, character of soil, and method of operation. Records of waste should be observed through several seasons in order to obtain a reliable average. The choice of canal reaches for seepage study should be made carefully, avoiding reaches where there is inflow of ground water or surface waste from higher irrigated land. The canal should be divided into reaches according to soil types encountered and gaging stations should be established at these points. All inflows and diversions should be measured by weir or measuring flume, and current-meter measurements, preferably in the form of "seepage runs" down the canal, should be made regularly and frequently, especially if there is any appreciable growth of algae or moss in the canal to change its hydraulic properties.

RANGE OF LOSSES .21 Seepage loss and waste in unlined canals range from as little as 0.34 feet depth per day on the wetted surface of the canal to 2.20 feet depth per day, or more, for loose gravelly soils under unusual conditions. Operating wastes range widely depending upon the adequacy of the canal capacity and the degree of care used in its operation and maintenance. Waste values may be negligible on excellent systems, but range upward to 50 percent of diversions on poor ones. An average would probably be less than 5 percent. Project system losses range from about 15 percent to 60 percent of the water diverted with the average falling between 25 and 40 percent. They are commonly least in clay soils; heaviest in gravel or exposed rock broken by joints, fractures, and solution channels. Lava rock is especially prone to heavy seepage losses. (See Chapter 7.2 for a more complete discussion.) Special consideration should be given to lining section of canal where losses are expected to be heavy in order to reduce losses. Studies to determine project water requirements should reflect these design considerations.

COMPUTING GROSS DIVERSION REQUIREMENT .22 After an estimate of conveyance loss and waste in percent of seasonal requirement has been made, seasonal diversion demand is obtained by dividing the farm delivery requirement ★in feet, by the quantity $(1 - L_c)$, where L_c is the loss and waste expressed as a decimal rather than as a percentage. The monthly distribution of L_c, canal losses and waste, is made by judgment, usually allowing an equal portion for each full month of the operating season. Allowance also is made for partial months and for priming losses at the beginning of the season.

$$D = \frac{R_f}{1 - L_c}$$

where

D = diversion demand (feet)

R_f = farm delivery requirement (feet)

L_c = canal losses and waste, expressed as a decimal ratio of canal losses and waste (feet) to diversion demand (feet).★

POINT OF DEMAND

.23 Where diversions are made at several successive points along the stream, it is desirable to compute the total diversion requirement at each point of diversion in acre-feet in order that proper allowance may be made for accretions to the supply from natural inflow or return flow from irrigated lands draining to the stream above the diversion point in computing the net demand on the stream or reservoir storage supply. Return flow is discussed in detail in Chapter 9.1.

CHAP. 4.1 IRRIGATION
APPENDIX I SAMPLE COMPUTATIONS--IRRIGATION WATER REQUIREMENTS

DETERMINING GROWING SEASON

.1 In order to illustrate the method of computation of the beginning and end of the growing season as used in the Lowry-Johnson method, two examples have been prepared. Example 1 on page 3, is for a condition where the break between temperatures below freezing and those above freezing is quite apparent. It should be noted that 1 day having a minimum temperature below 32° F was experienced after the designated start of the growing season (March 30). It is quite obvious, however, that this minor cold spell would be eliminated if the smoothing computations were carried out. Example 2 on page 4, illustrates a period when selection of the appropriate date for the start of the season cannot be made readily by inspection. Here it will be noted that the temperatures for some of the days before the start of the growing season are above freezing and that those for some of the days after it are below. The sharp drop in temperature on March 30 is not sufficient to cause the smoothed temperature to drop below 32° F. Even though the drop may be severe enough to cause damage to crops, it is probable that growth would have started before that time.

EFFECTIVE HEAT

.2 The computation of effective heat units may be made readily by working directly from the records. The daily excess of maximum temperatures above 32° F may be computed mentally and tabulated and totaled on an adding machine. The adding machine tapes may be mounted on sheets for use in the supporting data. The period between the beginning and end of the growing season may be totaled in this fashion also.

CONSUMPTIVE USE

.3 The average annual heat units derived for the period of study is then applied to the Lowry-Johnson curve of the relation between consumptive use and effective heat (see page 5) to obtain the corresponding average annual consumptive use. For this example the curve indicates an average annual consumptive use of 2.32 acre-feet per acre for an effective heat of 9550 day-degrees above 32° F. Because of the effect of factors other than temperature the method is not ordinarily considered accurate enough to warrant annual estimates of consumptive use for each year of the period of study corresponding to the effective heat for the individual years.

MONTHLY DISTRIBUTION OF CONSUMPTIVE USE & CROP REQUIREMENTS

.4 The average annual consumptive use (2.32 acre-feet per acre) obtained from the curve on page 5 is commonly distributed by months by reference to monthly values of consumptive use measured by valley inflow-outflow methods on the Boise or Rio Grande Projects, as given in Paragraph 4.1.10, or by reference to measured farm deliveries on irrigated projects of comparable climatic conditions, adequate water supply throughout the season, and efficient methods of application to maintain good soil moisture conditions without waste.

MONTHLY DISTRIBUTION OF
CONSUMPTIVE USE REQUIREMENTS

	Percent Consumptive Use in Month	Monthly Consumptive Use in Feet Depth
April	3	0.07
May	11	0.26
June	19	0.44
July	20	0.46
August	19	0.44
September	10	0.23
October	3	0.07
Winter period	15	0.35
Total	100	2.32

The crop requirement may be roughly approximated by reference to the monthly heat units with adjustment for differences in stage of growth. Experimental studies on the seasonal distribution of moisture requirements for individual crops are useful where the crop distribution does not follow closely the normal pattern for the climatic conditions.

COMPUTATIONS FOR ARID AREAS

.5 Effective precipitation is deducted from the consumptive use in order to derive the crop irrigation requirement. ★In arid areas where precipitation is a relatively minor portion of the total farm delivery requirement, computations for crop irrigation requirements may be based upon average monthly values of consumptive use and effective precipitation, rather than upon actual monthly records. Such brief studies are advantageous because of the saving of time and effort, yet they do not produce an appreciable error in the results.★ In preliminary or reconnaissance studies, an average annual value is sufficient to develop the annual irrigation diversion requirement which may be distributed by months by reference to average values in comparable areas. As an example of the brief type of study, representative of arid areas, the computations for the Hammond Project in New Mexico are shown on page 6.

COMPUTATIONS FOR SUBHUMID AREAS

.6 ★In subhumid areas where precipitation at times may exceed or approach the farm delivery requirement, a somewhat more detailed study is necessary. Because of the natural limitations in the accuracy of estimates of consumptive use, it generally is not considered worthwhile or advisable to utilize monthly or annual estimates of consumptive use even though the values will vary considerably from year to year. It is preferable to use an average consumptive use value, distributed by months, and to subtract the monthly effective precipitation to obtain the monthly crop irrigation requirement. However, for purposes of illustration, a detailed computation has been given on pages 7 to 9, inclusive, in which consumptive use has been computed for each month separately.★ The monthly values of effective precipitation have been estimated in accordance with the practices suggested in Subparagraph 4.1.12B, and adjusted to an amount less than the consumptive use for that month. In those months when the indicated effective precipitation is greater than the consumptive use requirements, the excess has been carried over into the subsequent months or period until utilized, except in cases when the soils are estimated to be unable to retain all of it for use. Even greater refinement could be effected by giving consideration to the timing of the excess within the month or by considering the daily rainfall distribution. For example, an excess occurring early in June is not so likely to be available to meet a deficiency of rainfall late in July as one occurring late in June. In these hypothetical computations, the consumptive use requirement was also computed on a detailed basis for each year from the annual effective heat, but the monthly distribution was made on the basis of an average percentage distribution. The crop irrigation requirement was then derived by subtracting the adjusted effective precipitation from the consumptive use.

DETERMINATION OF DETAIL REQUIRED

.7 These examples have been provided, not as models for the hydrologist to follow, but rather to suggest two degrees of detail in deriving irrigation water requirements. It will be necessary to consider each study individually to determine how much detail is required to obtain the desired results or is warranted by the available data.

CHAP. 4.1 IRRIGATION
APPENDIX I SAMPLE COMPUTATIONS--IRRIGATION WATER REQUIREMENTS

EXAMPLE 1
DETERMINATION OF START OF GROWING SEASON
FOR LOWRY-JOHNSON METHOD
AT A HYPOTHETICAL TEMPERATURE STATION

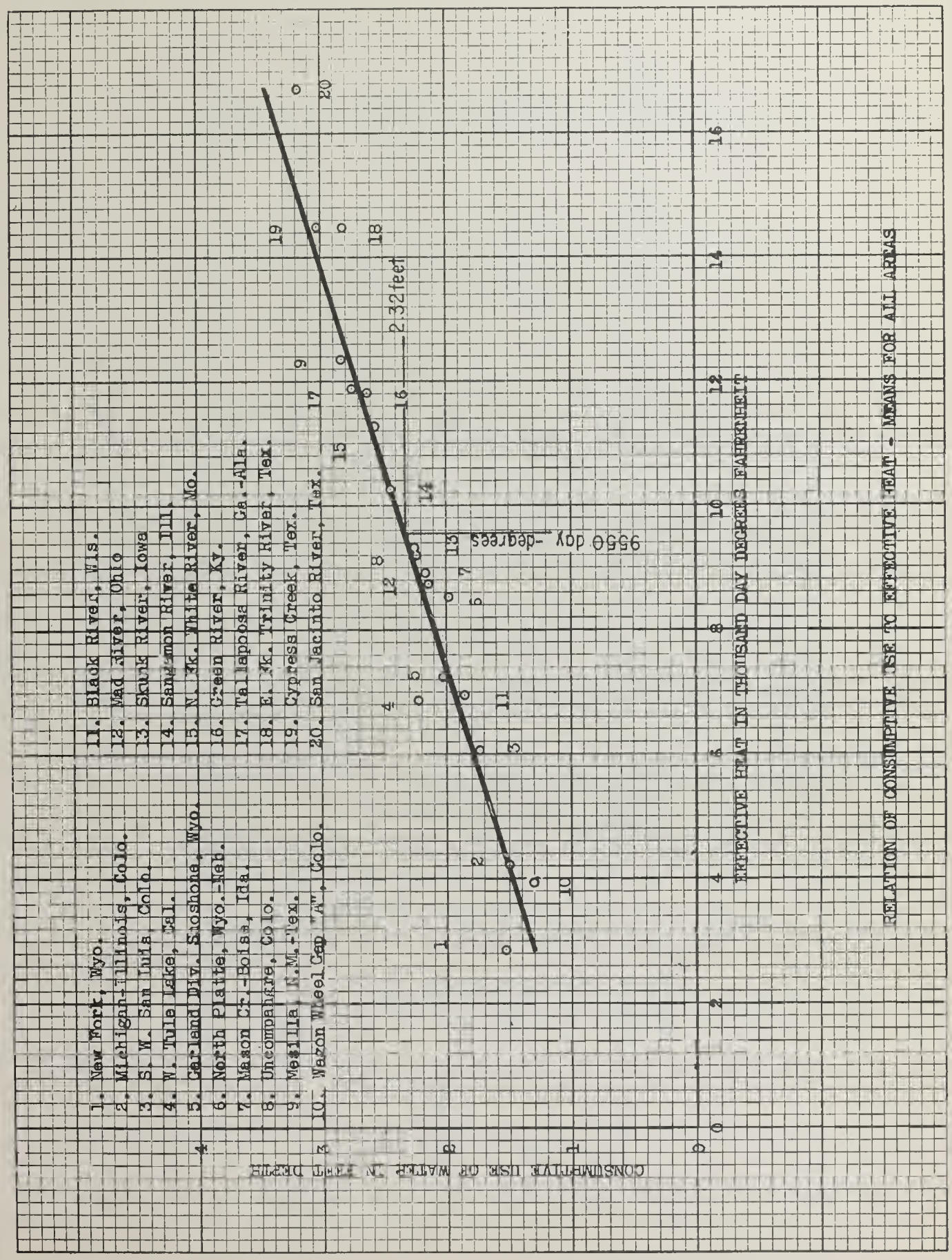
Date		Minimum Daily Temperature (degrees-F)	
March	1	16	
	2	12	
	3	17	
	4	20	
	5	23	(In this condition it is quite obvious when the growing season would start because there is a clear-cut division between days having freezing temperatures and those having warmer ones. Thus the date may be set without the necessity of smoothing computations.)
	6	21	
	7	27	
	8	30	
	9	32	
	10	33	
	11	29	
	12	25	
	13	20	
	14	24	
	15	26	
	16	23	
	17	31	
	18	30	
	19	30	
	20	32	Start of growing season
	21	34	
	22	37	
	23	40	
	24	36	
	25	40	
	26	41	
	27	41	
	28	39	
	29	35	
	30	31	
	31	33	
April	1	35	
	2	36	
	3	40	
	4	41	
	5	40	
	4	42	
	3	41	

CHAP. 4.1 IRRIGATION
APPENDIX I SAMPLE COMPUTATIONS--IRRIGATION WATER REQUIREMENTS

EXAMPLE 2
DETERMINATION OF START OF GROWING SEASON
FOR LOWRY-JOHNSON METHOD
AT A HYPOTHETICAL TEMPERATURE STATION

Date		Minimum Daily Temperature (degrees-F)	Smoothing Computations: 5-day Total	5-day Total of 5-day Totals	Daily Average	Mid-Period Date	Notes
March	1	25					32
	2	26					x25
	3	29					800 day-degrees
	4	35					
	5	32	147			Mar. 1	
	6	25	147			2	
	7	24	145			3	
	8	26	142			4	
	9	30	137	718	29	5	
	10	42	147	718	29	6	
	11	35	157	728	29	7	
	12	27	160	743	30	8	
	13	26	160	761	30	9	
	14	29	159	783	31	10	
	15	30	147	783	31	11	
	16	31	143	769	31	12	
	17	32	148	757	30	13	
	18	33	155	752	30	14	
	19 ---	32	158	751	30	15	
	20	33	161	765	31	16	
	21	31	161	783	31	17	
	22	30	159	794	32-	18	
	23	33	159	798	32-	19	
	24	35	162	802	32+	20	Start of
	25	40	169	810	32+	21	growing
	26	38	176	825	33	22	season
	27	36	182	848	34	23	
	28	34	183	872	35	24	
	29	30	178	888	36	25	
	30	26	164	883	35	26	
	31	31	157	864	35	27	
April	1	35	156	838	34	28	
	2	37	159	814	33	29	
	3	38	167	803	32+	30	
	4	38	179	818	33	31	
	5	40	188	849	34	Apr. 1	
	6	39	192	885	35	2	
	7	42	197	923	37	3	
	8	44	203	959	38	4	
	9	45	210	990	40	5	

CHAP. 4.1 IRRIGATION
APPENDIX I SAMPLE COMPUTATIONS--IRRIGATION WATER REQUIREMENTS



DERIVATION OF WATER REQUIREMENTS
FOR THE HAMMOND PROJECT, NEW MEXICO

Month	Consumptive Use Feet	Effective Precipitation Feet#	Consumptive Use of Irrigation Water Feet	Farm Delivery Reqmt. Feet	Conveyance Losses and Waste		Diversion Requirement		Total Project Demand## AC.-FT.
					Percent	Feet	Feet	Percent	
Winter	0.35	0.16							
April*	.07	.02	** 0.24	0.37	56	0.47	0.84	17	3,100
May	.26	.04	.22	.34	47	.30	.64	13	2,400
June	.44	.01	.43	.66	30½	.29	.95	19	3,500
July	.46	.03	.43	.66	30½	.29	95	19	3,500
August	.44	.06	.38	.58	32½	.28	.86	17	3,100
September	.23	.03	.20	.30	46½	.26	.56	11	2,100
October*	.07	.01	.06	.09	55	.11	.20	4	700
Total	2.32	0.36	1.96	3.00	40	2.00	5.00	100	18,400

80% of the average for the 5 driest years of record at Bloomfield, New Mexico.

* Irrigation season April 7 to October 21 (198 days). Growing season April 24 to October 21.

** Winter deficiency to be made up in April.

Net irrigated area of 3,680 acres.

COMPUTATION OF EFFECTIVE HEAT AND CONSUMPTIVE USE
FOR A HYPOTHETICAL PROJECT IN SUBHUMID AREA

	Effective Heat--Day Degrees													Consumptive Use-
Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	in Feet Depth*
1919	--	--	578	954	1,266	1,554	1,954	1,947	1,671	1,250	194	--	11,368	2.63
1920	--	--	522	910	1,366	1,656	1,864	1,744	1,611	1,328	264	--	11,265	2.59
1921	--	20	1,070	1,128	1,485	1,635	1,976	2,023	1,755	1,402	320	--	12,814	2.84
1922	--	--	434	1,052	1,352	1,713	1,784	2,026	1,736	1,415	558	--	12,070	2.74
1923	--	--	221	1,062	1,246	1,594	1,844	1,945	1,572	962	516	--	10,962	2.56
1924	--	--	132	1,158	1,258	1,708	1,824	1,916	1,491	1,369	504	--	11,360	2.63
1925	--	--	812	1,244	1,404	1,828	1,975	1,906	1,602	817	147	--	11,735	2.68
1926	--	--	86	930	1,491	1,684	1,938	1,988	1,484	1,226	224	--	11,051	2.57
1927	--	--	424	1,100	1,386	1,542	1,866	1,592	1,522	1,406	420	--	11,258	2.61
1928	--	--	853	1,041	1,440	1,414	1,807	1,886	1,566	1,306	572	--	11,885	2.70
1929	--	--	740	1,148	1,244	1,554	1,820	1,891	1,500	1,181	174	--	11,252	2.61
1930	--	--	280	1,304	1,367	1,598	2,038	1,945	1,602	1,127	778	--	12,039	2.73
1931	--	--	130	1,077	1,298	1,836	2,034	1,844	1,862	1,336	756	160	12,333	2.77
1932	--	--	239	1,209	1,492	1,678	1,978	1,916	1,544	1,192	232	--	11,480	2.64
1933	--	--	684	1,176	1,466	2,024	1,990	1,826	1,550	1,256	853	--	12,825	2.84
1934	--	--	395	1,239	1,604	1,942	2,258	2,151	1,455	1,360	786	--	13,191	2.90
1935	--	44	1,024	957	1,178	1,541	2,096	2,028	1,574	1,084	278	--	11,804	2.69
1936	--	--	663	1,206	1,508	1,881	2,222	2,224	1,605	1,091	257	--	12,657	2.82
1937	--	--	208	1,094	1,488	1,698	2,023	2,140	1,612	1,232	428	--	11,923	2.70
1938		60	1,008	1,119	1,360	1,653	2,001	2,064	1,692	1,572	408	--	12,937	2.86
1939	--	--	662	1,128	1,632	1,719	2,090	1,829	1,780	1,422	675	--	12,937	2.86
1940	--	--	611	1,044	1,425	1,686	2,045	1,662	1,321	1,472	318	--	11,784	2.69
1941	--	--	399	1,126	1,556	1,598	1,938	1,880	1,560	1,115	753	228	12,153	2.75
1942	--	--	552	1,194	1,375	1,560	1,931	1,747	1,410	1,217	726	--	11,712	2.68
1943	--	--	349	1,301	1,266	1,694	1,910	2,098	1,540	1,217	375	--	11,750	2.68
1944	--	--	198	887	1,464	1,749	1,840	1,848	1,540	1,260	740	--	11,526	2.64
1945	--	15	1,030	990	1,334	1,444	1,816	1,882	1,567	1,203	602	--	11,883	2.70
Totals	--	139	14,304	29,778	37,751	45,183	52,862	51,948	42,924	33,818	12,858	388	321,953	73.11
Average	-	5	530	1,103	1,398	1,673	1,958	1,924	1,590	1,253	476	14	11,924	2.71

* From Lowry-Johnson Curve, Appendix I, page 5.

CHAP. 4.1 IRRIGATION
APPENDIX I SAMPLE COMPUTATIONS--IRRIGATION WATER REQUIREMENTS

DERIVATION OF ADOPTED CONSUMPTIVE USE RATE
FOR A HYPOTHETICAL PROJECT IN SUBHUMID AREAS

	Evaporation Rate at Temperature Station (Percent)	Effective Heat at Temperature Station Entire Yr. (Percent)	Computed Effective Heat (Percent)	Consumptive Use Rate from Lowry & Johnson Report 1/ (Percent)	Adopted Consumptive Use Rate for Project (Percent)
April	8	8	9	8.6	8
May	10	10	12	9.3	11
June	12	12	14	13.3	14
July	16	15	16	18.3	18
August	14	14	16	17.5	17
September	11	12	13	11.8	11
October	9	9	11	6.5	6
Nov.-Mar.	20	20	9	14.7	15
Total	100	100	100	100.0	100

1/ Monthly distribution of consumptive use for the Boise Project, Idaho, and the Mesilla Valley, New Mexico are given in "Consumptive Use of Water for Agriculture" by Lowry and Johnson, ASCE Transactions, 1942, Vol. 107, page 1243.

MID AREA

Year	November -			ptember			October					Totals			
	Carry-over from Previous Month	Effective Precipitation	Consumptive Use	Consumptive Use Requirements	Effective Precipitation Used	Crop Irrigation Requirements	Carry-over from Previous Month	Effective Precipitation	Consumptive Use Requirements	Effective Precipitation Used	Crop Irrigation Requirements		Effective Precipitation	Consumptive Use Requirements	Effective Precipitation Used	Crop Irrigation Requirements
	1 (a)	2	3	3	4 (b)	5 (c)	1 (a)	2	3	4 (b)	5 (c)		2	3	4	5 (c)
1919				0.29	0.12	0.17	0	0.14	0.16	0.14	0.02		1.29	2.24	1.29	0.95
1920	0	0.41	0.3	0.28	0.12	0.16	0	0.14	0.16	0.14	0.02		1.81	2.59	1.81	0.78
1921	0	0.34	0.4	0.31	0.23	0.08	0	0.05	0.17	0.05	0.12		1.56	2.83	1.56	1.27
1922	0	0.48	0.4	0.30	0.25	0.05	0	0.18	0.17	0.17	0		2.02	2.74	2.01	0.73
1923	0.01	0.43	0.4	0.28	0.23	0.05	0	0.25	0.15	0.15	0		2.05	2.58	1.96	0.62
1924	0.10	0.35	0.3	0.29	0.06	0.23	0	0.07	0.16	0.07	0.09		1.50	2.62	1.60	1.02
1925	0	0.25	0.4	0.30	0.28	0.02	0	0.13	0.16	0.13	0.03		1.74	2.68	1.74	0.94
1926	0	0.39	0.3	0.28	0.27	0.01	0	0.22	0.16	0.16	0		1.62	2.57	1.56	1.01
1927	0.06	0.54	0.3	0.29	0.21	0.08	0	0.06	0.16	0.06	0.10		1.97	2.61	2.00	0.61
1928	0	0.28	0.4	0.30	0.16	0.14	0	0.08	0.16	0.08	0.08		1.78	2.70	1.78	0.92
1929	0	0.59	0.3	0.29	0.10	0.19	0	0.29	0.16	0.16	0		2.31	2.61	2.12	0.49
1930	0.13	0.30	0.4	0.30	0.30	0	0.03	0.13	0.16	0.16	0		1.90	2.73	2.03	0.70
1931	0	0.47	0.4	0.30	0.13	0.17	0	0.08	0.17	0.08	0.09		1.63	2.76	1.63	1.13
1932	0	0.56	0.4	0.29	0.15	0.14	0	0.08	0.16	0.08	0.08		2.04	2.65	2.04	0.61
1933	0	0.20	0.4	0.31	0.14	0.17	0	0.01	0.17	0.01	0.16		1.35	2.83	1.35	1.48
1934	0	0.30	0.4	0.32	0.28	0.04	0	0.14	0.18	0.14	0.04		1.41	2.89	1.41	1.48
1935	0	0.42	0.4	0.30	0.22	0.08	0	0.20	0.16	0.16	0		1.99	2.71	1.95	0.76
1936	0.04	0.21	0.4	0.31	0.31	0	0	0.15	0.17	0.15	0.02		1.38	2.81	1.42	1.39
1937	0	0.38	0.4	0.30	0.18	0.12	0	0.19	0.16	0.16	0		1.95	2.71	1.92	0.79
1938	0.03	0.40	0.4	0.31	0.15	0.16	0	0	0.17	0	0.17		1.84	2.85	1.87	0.98
1939	0	0.48	0.4	0.31	0	0.31	0	0.10	0.17	0.10	0.07		1.54	2.86	1.54	1.32
1940	0	0.35	0.4	0.30	0.19	0.11	0	0.10	0.16	0.10	0.06		1.80	2.70	1.80	0.90
1941	0	0.67	0.4	0.30	0.30	0	0.04	0.34	0.16	0.16	0		2.34	2.75	2.06	0.69
1942	0.20	0.46	0.4	0.30	0.30	0	0.04	0.30	0.16	0.16	0		2.35	2.68	2.19	0.49
1943	0.18	0.40	0.4	0.30	0.15	0.15	0	0.28	0.16	0.16	0		1.77	2.68	1.83	0.85
1944	0.12	0.61	0.4	0.29	0.22	0.07	0	0.09	0.16	0.09	0.07		2.30	2.64	2.16	0.48
1945	0	0.77	0.4	0.30	0.30	0	0.01	0.07	0.16	0.08	0.08		2.22	2.70	1.93	0.77
Total	0.87	11.04	10.5	8.05	5.35(f)	2.70	0.12	3.87	4.40	3.10(f)	1.30		49.46	72.72	48.56	24.16
Unadjusted total	0.89						0.12									
Average		0.42	0.4	0.30	0.20	0.10		0.14	0.16	0.11	0.05		1.83	2.69	1.80	0.90
Percent		23	15	11	11	11		8	6	6	6		100	100	100	100

(a)

(b)

(c)

(f)

The effective precipitation has been determined by a curve passed through the following points:

Precipitation in Inches:

Actual	Effective
1	0.95
2	1.85
3	2.67
4	3.33
5	3.82
6	4.02
7 and over	4.10

CHAP. 4.1 IRRIGATION
APPENDIX I SAMPLE COMPUTATIONS--IRRIGATION WATER REQUIREMENTS

COMPUTATION OF THE CROP IRRIGATION REQUIREMENTS IN FEET DEPTH FOR A HYPOTHETICAL PROJECT IN SUBHUMID AREA

Year	November - March					April					May					June					July					August					September					October					Totals			
	Carry-over from Previous Month	Effective Precipitation	Consumptive Use Requirements	Effective Precipitation Used	Crop Irrigation Requirements	Carry-over from Previous Month	Effective Precipitation	Consumptive Use Requirements	Effective Precipitation Used	Crop Irrigation Requirements	Carry-over from Previous Month	Effective Precipitation	Consumptive Use Requirements	Effective Precipitation Used	Crop Irrigation Requirements	Carry-over from Previous Month	Effective Precipitation	Consumptive Use Requirements	Effective Precipitation Used	Crop Irrigation Requirements	Carry-over from Previous Month	Effective Precipitation	Consumptive Use Requirements	Effective Precipitation Used	Crop Irrigation Requirements	Carry-over from Previous Month	Effective Precipitation	Consumptive Use Requirements	Effective Precipitation Used	Crop Irrigation Requirements	Carry-over from Previous Month	Effective Precipitation	Consumptive Use Requirements	Effective Precipitation Used	Crop Irrigation Requirements	Carry-over from Previous Month	Effective Precipitation	Consumptive Use Requirements	Effective Precipitation Used	Crop Irrigation Requirements		Effective Precipitation	Consumptive Use Requirements	Effective Precipitation Used	Crop Irrigation Requirements
	1 (a)	2	3	4 (b)	5 (c)	1 (a)	2	3	4 (b)	5 (c)	1 (a)	2	3	4 (b)	5 (c)	1 (a)	2	3	4 (b)	5 (c)	1 (a)	2	3	4 (b)	5 (c)	1 (a)	2	3	4 (b)	5 (c)	1 (a)	2	3	4 (b)	5 (c)	1 (a)	2	3	4 (b)	5 (c)		2	3	4	5 (c)
1919							0.32	0.21	0.21	0	0.11	0.23	0.29	0.29	0	0.05	0.32	0.37	0.37	0	0	0.14	0.47	0.14	0.33	0	0.02	0.45	0.02	0.43	0	0.12	0.29	0.12	0.17	0	0.14	0.16	0.14	0.02		1.29	2.24	1.29	0.95
1920	0	0.41	0.39	0.39	0	0.02	0.31	0.21	0.21	0	0.12	0.26	0.28	0.28	0	0.10	0.15	0.36	0.25	0.11	0	0.18	0.47	0.18	0.29	0	0.24	0.44	0.24	0.20	0	0.12	0.28	0.12	0.16	0	0.14	0.16	0.14	0.02		1.81	2.59	1.81	0.78
1921	0	0.34	0.42	0.34	0.08	0	0.18	0.23	0.18	0.05	0	0.20	0.31	0.20	0.11	0	0.31	0.40	0.31	0.09	0	0.05	0.51	0.05	0.46	0	0.20	0.48	0.20	0.28	0	0.23	0.31	0.23	0.08	0	0.05	0.17	0.05	0.12		1.56	2.83	1.56	1.27
1922	0	0.48	0.41	0.41	0	0.07	0.31	0.22	0.22	0	0.16	0.32	0.30	0.30	0	0.18	0.18	0.38	0.36	0.02	0	0.28	0.49	0.28	0.21	0	0.02	0.47	0.02	0.45	0	0.25	0.30	0.25	0.05	0	0.18	0.17	0.17	0		2.02	2.74	2.01	0.73
1923	0.01	0.43	0.40	0.40	0	0.04	0.18	0.21	0.21	0	0.01	0.34	0.28	0.28	0	0.07	0.34	0.36	0.36	0	0.05	0.22	0.46	0.27	0.19	0	0.06	0.44	0.06	0.38	0	0.23	0.28	0.23	0.05	0	0.25	0.15	0.15	0		2.05	2.58	1.96	0.62
1924	0.10	0.35	0.38	0.38	0	0.07	0.29	0.21	0.21	0	0.15	0.16	0.29	0.29	0	0.02	0.08	0.37	0.10	0.27	0	0.19	0.47	0.19	0.28	0	0.30	0.45	0.30	0.15	0	0.06	0.29	0.06	0.23	0	0.07	0.16	0.07	0.09		1.50	2.62	1.60	1.02
1925	0	0.25	0.40	0.25	0.15	0	0.21	0.21	0.21	0	0	0.16	0.29	0.16	0.13	0	0.32	0.38	0.32	0.06	0	0.17	0.48	0.17	0.31	0	0.22	0.46	0.22	0.24	0	0.28	0.30	0.28	0.02	0	0.13	0.16	0.13	0.03		1.74	2.68	1.74	0.94
1926	0	0.39	0.39	0.39	0	0	0.10	0.20	0.10	0.10	0	0.10	0.28	0.10	0.18	0	0.20	0.36	0.20	0.16	0	0.15	0.46	0.15	0.31	0	0.19	0.44	0.19	0.25	0	0.27	0.28	0.27	0.01	0	0.22	0.16	0.16	0		1.62	2.57	1.56	1.01
1927	0.06	0.54	0.39	0.39	0	0.20	0.23	0.21	0.21	0	0.20	0.08	0.29	0.28	0.01	0	0.34	0.36	0.34	0.02	0	0.17	0.47	0.17	0.30	0	0.34	0.44	0.34	0.10	0	0.21	0.29	0.21	0.08	0	0.06	0.16	0.06	0.10		1.97	2.61	2.00	0.61
1928	0	0.28	0.40	0.28	0.12	0	0.19	0.21	0.19	0.02	0	0.19	0.30	0.19	0.11	0	0.34	0.38	0.34	0.04	0	0.30	0.49	0.30	0.19	0	0.24	0.46	0.24	0.22	0	0.16	0.30	0.16	0.14	0	0.08	0.16	0.08	0.08		1.78	2.70	1.78	0.92
1929	0	0.59	0.39	0.39	0	0.20	0.22	0.21	0.21	0	0.20	0.34	0.29	0.29	0	0.20	0.29	0.36	0.36	0	0.13	0.33	0.47	0.46	0.01	0	0.15	0.44	0.15	0.29	0	0.10	0.29	0.10	0.19	0	0.29	0.16	0.16	0		2.31	2.61	2.12	0.49
1930	0.13	0.30	0.41	0.41	0	0.02	0.20	0.22	0.22	0	0	0.33	0.30	0.30	0	0.03	0.23	0.38	0.26	0.12	0	0.13	0.49	0.13	0.36	0	0.25	0.47	0.25	0.22	0	0.33	0.30	0.30	0	0.03	0.13	0.16	0.16	0		1.90	2.73	2.03	0.70
1931	0	0.47	0.41	0.41	0	0.06	0.19	0.22	0.22	0	0.03	0.20	0.30	0.23	0.07	0	0.24	0.39	0.24	0.15	0	0.07	0.50	0.07	0.43	0	0.25	0.47	0.25	0.22	0	0.13	0.30	0.13	0.17	0	0.08	0.17	0.08	0.09		1.63	2.76	1.63	1.13
1932	0	0.56	0.41	0.41	0	0.15	0.10	0.21	0.21	0	0.04	0.26	0.29	0.29	0	0.01	0.33	0.37	0.34	0.03	0	0.32	0.47	0.32	0.15	0	0.24	0.45	0.24	0.21	0	0.15	0.29	0.15	0.14	0	0.08	0.16	0.08	0.08		2.04	2.65	2.04	0.61
1933	0	0.20	0.42	0.20	0.22	0	0.07	0.23	0.07	0.16	0	0.33	0.31	0.31	0	0.02	0.05	0.40	0.07	0.33	0	0.22	0.51	0.22	0.29	0	0.33	0.48	0.33	0.15	0	0.14	0.31	0.14	0.17	0	0.01	0.17	0.01	0.16		1.35	2.83	1.35	1.48
1934	0	0.30	0.43	0.30	0.13	0	0.02	0.23	0.02	0.21	0	0.29	0.32	0.29	0.03	0	0.21	0.40	0.21	0.19	0	0.10	0.52	0.10	0.42	0	0.07	0.49	0.07	0.42	0	0.28	0.32	0.28	0.04	0	0.14	0.18	0.14	0.04		1.41	2.89	1.41	1.48
1935	0	0.42	0.42	0.42	0	0	0.03	0.22	0.03	0.19	0	0.33	0.29	0.29	0	0.04	0.28	0.38	0.32	0.06	0	0.28	0.48	0.28	0.20	0	0.23	0.46	0.23	0.23	0	0.22	0.30	0.22	0.08	0	0.20	0.16	0.16	0		1.99	2.71	1.95	0.76
1936	0.04	0.21	0.41	0.25	0.16	0	0.11	0.23	0.11	0.12	0	0.34	0.31	0.31	0	0.03	0.12	0.39	0.15	0.24	0	0.03	0.51	0.03	0.48	0	0.11	0.48	0.11	0.37	0	0.31	0.31	0.31	0	0	0.15	0.17	0.15	0.02		1.38	2.81	1.42	1.39
1937	0	0.38	0.41	0.38	0.03	0	0.03	0.21	0.03	0.18	0	0.30	0.30	0.30	0	0	0.30	0.38	0.30	0.08	0	0.28	0.49	0.28	0.21	0	0.29	0.46	0.29	0.17	0	0.18	0.30	0.18	0.12	0	0.19	0.16	0.16	0		1.95	2.71	1.92	0.79
1938	0.03	0.40	0.42	0.42	0	0.01	0.17	0.23	0.18	0.05	0	0.34	0.32	0.32	0	0.02	0.34	0.40	0.36	0.04	0	0.21	0.51	0.21	0.30	0	0.23	0.49	0.23	0.26	0	0.15	0.31	0.15	0.16	0	0	0.17	0	0.17		1.84	2.85	1.87	0.98
1939	0	0.48	0.43	0.43	0	0.05	0.08	0.23	0.13	0.10	0	0.14	0.32	0.14	0.18	0	0.29	0.40	0.29	0.11	0	0.12	0.51	0.12	0.39	0	0.33	0.49	0.33	0.16	0	0	0.31	0	0.31	0	0.10	0.17	0.10	0.07		1.54	2.86	1.54	1.32
1940	0	0.35	0.41	0.35	0.06	0	0.24	0.22	0.22	0	0.02	0.27	0.29	0.29	0	0	0.32	0.38	0.32	0.06	0	0.05	0.48	0.05	0.43	0	0.28	0.46	0.28	0.18	0	0.19	0.30	0.19	0.11	0	0.10	0.16	0.10	0.06		1.80	2.70	1.80	0.90
1941	0	0.67	0.41	0.41	0	0.20	0.11	0.22	0.22	0	0.09	0.13	0.30	0.22	0.08	0	0.34	0.39	0.34	0.05	0	0.07	0.50	0.07	0.43	0	0.34	0.47	0.34	0.13	0	0.34	0.30	0.30	0	0.04	0.34	0.16	0.16	0		2.34	2.75	2.06	0.69
1942	0.20	0.46	0.40	0.40	0	0.20	0.33	0.21	0.21	0	0.20	0.14	0.29	0.29	0	0.05	0.34	0.38	0.38	0	0.01	0.10	0.48	0.11	0.37	0	0.34	0.46	0.34	0.12	0	0.34	0.30	0.30	0	0.04	0.30	0.16	0.16	0		2.35	2.68	2.19	0.49
1943	0.18	0.40	0.40	0.40	0	0.18	0.11	0.21	0.21	0	0.08	0.32	0.29	0.29	0	0.11	0.21	0.38	0.32	0.06	0	0.24	0.48	0.24	0.24	0	0.06	0.46	0.06	0.40	0	0.15	0.30	0.15	0.15	0	0.28	0.16	0.16	0		1.77	2.68	1.83	0.85
1944	0.12	0.61	0.40	0.40	0	0.20	0.34	0.21	0.21	0	0.20	0.24	0.29	0.29	0	0.15	0.16	0.37	0.31	0.06	0	0.34	0.47	0.34	0.13	0	0.30	0.45	0.30	0.15	0	0.22	0.29	0.22	0.07	0	0.09	0.16	0.09	0.07		2.30	2.64	2.16	0.48
1945	0	0.77	0.40	0.40	0	0.20	0.33	0.21	0.21	0	0.20	0.15	0.30	0.30	0	0.05	0.18	0.38	0.23	0.15	0	0.24	0.49	0.24	0.25	0	0.17	0.46	0.17	0.29	0	0.31	0.30	0.30	0	0.01	0.07	0.16	0.08	0.08		2.22	2.70	1.93	0.77
Total	0.87	11.04	10.56	9.61(f)	0.95	1.87	5.00	5.84	4.66(f)	1.18	1.81	6.49	8.02	7.12(f)	0.90	1.13	6.81	10.25	7.75(f)	2.50	0.19	4.98	13.13	5.17(f)	7.96	0	5.80	12.47	5.80(f)	6.67	0	5.47	8.05	5.35(f)	2.70	0.12	3.87	4.40	3.10(f)	1.30		49.46	72.72	48.56	24.16
Unadjusted total	0.89					2.30					2.21					1.18					0.19					0					0					0.12									
Average		0.42	0.41	0.37	0.04		0.19	0.22	0.17	0.04		0.24	0.30	0.26	0.03		0.25	0.38	0.29	0.09		0.18	0.49	0.19	0.29		0.21	0.46	0.21	0.25		0.20	0.30	0.20	0.10		0.14	0.16	0.11	0.05		1.83	2.69	1.80	0.90
Percent		23	15	21	5		10	8	9	5		13	11	14	3		14	14	16	10		10	18	11	32		11	17	12	28		11	11	11	11		8	6	6	6		100	100	100	100

(a) Rainfall, including carry-over, in excess of consumptive use requirements carried over into subsequent month or months. Carry-over (accumulated precipitation in excess of consumptive use requirements) by more than 0.20 of a foot considered run-off.

(b) Sum of Columns 1 (adjusted) + 2 or Column 3 (whichever is less).

(c) Column 3 - Column 4.

(f) Total: Column 1 adjusted + Column 2 - Column 1 (following month) unadjusted, equals Column 4.

The effective precipitation has been determined by a curve passed through the following points:

Precipitation in Inches: Actual	Effective
1	0.95
2	1.85
3	2.67
4	3.33
5	3.82
6	4.02
7 and over	4.10

CHAP. 4.1 IRRIGATION
APPENDIX I SAMPLE COMPUTATIONS--IRRIGATION WATER REQUIREMENTS

COMPUTATIONS FOR
ADJUSTED EFFECTIVE PRECIPITATION IN FEET DEPTH
FOR HYPOTHETICAL PROJECT IN SUBHUMID AREAS

Year	Nov.-Mar.	April	May	June	July	Aug.	Sept.	Oct.	Total
1919	0.36 4/	0.21 1/	0.29 1/	0.37 1/	0.16	0.02	0.12	0.14	1.67
1920	.39 2/	.21 1/	.28 1/	.23	.18	.24	.12	.14	1.79
1921	.34	.18	.20	.31	.05	.20	.21	.04	1.53
1922	.41 2/	.22 1/	.30 1/	.29	.28	.02	.25	.17 2/	1.94
1923	.40 3/	.21	.28 2/	.34	.22	.06	.23	.15 3/	1.89
1924	.38 2/	.21 1/	.24	.08	.19	.30	.06	.07	1.53
1925	.25	.21	.16	.32	.17	.22	.28	.13	1.74
1926	.39 1/	.11	.10	.20	.15	.19	.27	.16 2/	1.57
1927	.39 2/	.21 1/	.10	.34	.17	.34	.21	.06	1.82
1928	.28	.19	.19	.34	.30	.24	.16	.08	1.78
1929	.39 2/	.21 2/	.29 1/	.34	.33	.15	.10	.16 2/	1.97
1930	.30	.20	.30 1/	.26	.13	.25	.30 3/	.16	1.90
1931	.41 3/	.22	.20	.20	.07	.25	.13	.08	1.56
1932	.41 2/	.10	.26	.33	.32	.24	.15	.08	1.89
1933	.20	.07	.31 1/	.07	.22	.33	.14	.01	1.35
1934	.30	.02	.29	.21	.10	.07	.28	.14	1.41
1935	.42	.03	.29 1/	.32	.28	.23	.22	.16 2/	1.95
1936	.21	.11	.31 1/	.15	.03	.11	.31	.15	1.38
1937	.38	.03	.30	.30	.28	.29	.18	.16 2/	1.92
1938	.40	.17	.32 1/	.36	.21	.23	.15	0	1.84
1939	.43 1/	.13	.14	.29	.12	.33	0	.10	1.54
1940	.35	.22 1/	.29	.32	.05	.28	.19	.10	1.80
1941	.41 2/	.11	.13	.34	.07	.34	.30 2/	.16 2/	1.86
1942	.40 2/	.21 1/	.26	.34	.10	.34	.30 2/	.16 3/	2.11
1943	.40 2/	.11	.29 1/	.24	.24	.06	.15	.16 3/	1.65
1944	.40 2/	.21 1/	.29 1/	.34	.34	.30	.22	.09	2.19
1945	.40 2/	.21 1/	.27	.18	.24	.17	.30 1/	.08	1.85
Total	9.80	4.31	6.68	7.41	5.00	5.80	5.33	3.09	47.42
Average	0.36	0.16	0.25	0.27	0.19	0.21	0.20	0.11	1.75

1/ Rainfall in excess of consumptive use requirements carried over into subsequent month or period.

2/ Rainfall in excess of consumptive use requirements considered runoff when no deficiency occurs in subsequent month or period.

3/ Rainfall in excess of consumptive use requirements is carried over to the subsequent month or period to satisfy consumptive use deficiencies and that in excess of these deficiencies considered runoff.

4/ Estimated as average of other 26 years.

CHAP. 4.1 IRRIGATION
APPENDIX I SAMPLE COMPUTATIONS--IRRIGATION WATER REQUIREMENTS

DERIVATION 1/ OF THE
CROP IRRIGATION REQUIREMENTS IN FEET DEPTH
FOR A HYPOTHETICAL PROJECT IN SUBHUMID AREA

Irrig. Season	April 2/	May	June	July	Aug.	Sept.	Oct.	Total
1919	0.05 3/	0.00	0.00	0.31	0.43	0.17	0.02	0.98
1920	0	0	.08	.29	.20	.16	.02	.75
1921	.13	.11	.09	.46	.28	.10	.13	1.30
1922	0	0	.09	.21	.45	.05	0	0.80
1923	0	0	.02	.22	.38	.05	0	0.67
1924	0	.05	.29	.28	.15	.23	.09	1.09
1925	.15	.13	.06	.31	.24	.02	.03	0.94
1926	.09	.18	.16	.31	.25	.01	0	1.00
1927	0	.19	.02	.30	.10	.08	.10	0.79
1928	.14	.11	.04	.19	.22	.14	.08	0.88
1929	0	0	.02	.14	.29	.19	0	0.64
1930	.13	0	.12	.36	.22	0	0	0.83
1931	0	.10	.19	.43	.22	.17	.09	1.20
1932	.11	.03	.04	.15	.21	.14	.08	0.76
1933	.38	0	.33	.29	.16	.17	.16	1.39
1934	.34	.03	.19	.42	.42	.04	.04	1.48
1935	.19	0	.06	.20	.23	.08	0	0.76
1936	.32	0	.24	.48	.37	0	.02	1.43
1937	.20	0	.08	.21	.17	.12	0	0.78
1938	.08	0	.04	.20	.26	.16	.17	0.91
1939	.10	.18	.11	.39	.16	.31	.07	1.32
1940	.06	0	.06	.43	.18	.11	.06	0.90
1941	.11	.17	.05	.43	.13	0	0	0.89
1942	0	.03	.04	.38	.12	0	0	0.57
1943	.10	0	.14	.24	.40	.15	0	1.03
1944	0	0	.03	.13	.15	.07	.07	0.45
1945	0	.03	.20	.25	.29	0	.08	0.85
Total								25.39
Average								0.94

1/ Values shown in this tabulation are obtained by deducting monthly adjusted effective precipitation values on Sheet 5 from the corresponding values of monthly consumptive use requirements on Sheet 3.

2/ Includes requirements of Nov.-Mar. period in addition to April requirements.

3/ Nov.-Mar. consumptive use estimated as average of other 26 years.

CHAP. 4.2 HYDROPOWER PRODUCTION

.1 Hydropower utilizes the energy of falling water. The water itself is not changed sensibly in character nor diminished in amount except for evaporation. The power produced is a function of head, discharge, and turbine efficiency. Turbines may be direct-connected to the load as in the case of some pumping plants and industrial machinery, or, as more commonly used on Bureau of Reclamation projects, they may be connected to generators to produce electrical energy. GENERAL

.2 The total available electrical energy may be determined by the following commonly used formula: POWER FORMULAE

$$E = 1.025\ QHe$$

where E = Energy in kilowatt-hours

Q = Total quantity of water in acre-feet

H = Static head in feet

e = Overall efficiency expressed as a decimal.

This formula is valuable in making preliminary estimates of the potential power production of streams. In most Bureau of Reclamation studies it is necessary to determine how that power can best be produced, whether: (1) as firm power available at all times to meet load demands; (2) as secondary power requiring the development of special loads to utilize it; (3) as peaking power to meet system demands not readily supplied by fuel plants; or (4) as firming power coordinated into system production to raise the level of firm output. No single power development should be considered on an independent or isolated operation basis if operation in a coordinated or interconnected power system is probable. Consideration of the operation of a powerplant as a unit in a coordinated or interconnected power system is an extremely complex problem, and careful consideration should be given to all contributing factors such as firming possibilities, coordinated operation of reservoirs, and power market requirements. Studies are generally made by assuming the power installation and checking against available water supply during critical periods to determine to what extent that installation can be supplied. This can be done easily in the case of constant-head run-of-river plants by examining the discharge records, and preparing a flow-duration curve, discharge against percent of time. If storage is used to regulate the flow the study becomes quite complex and must be solved by trial using the current mean monthly water requirement fixed by the available head and the corresponding turbine efficiency. The common power equation in horsepower and kilowatt units is stated below in terms of the quantity of water:

$$Q = \frac{8.8\ hp}{He}; \text{ or } Q = \frac{11.8\ kw}{He}$$

where Q = Discharge in cubic feet per second

hp = Power in horsepower

kw = Power in kilowatts
(1 horsepower = 0.746 kilowatts)

H = Static head in feet

e = Overall efficiency expressed as a decimal.

Important features of these terms are discussed below:

A. Power output is a variable with the installed capacity of the generators as a normal upper limit and the firm power demand as a lower limit. The firm power demand follows a cyclic load curve with daily and seasonal POWER

POWER (Cont.)

peaks but in monthly water supply studies it is customary to assume that the variable daily load represents an average continuous firm power output for the month and the monthly average varied to conform to the seasonal load curve. Conditions of operation discussed in Part 5, Project Operation Studies, of this Volume, dictate whether the water requirement is for this firm continuous power output, for continuous operation at plant capacity, or for some intermediate output. Plant capacity is frequently set at firm peak estimated by applying a regional load factor to the estimated continuous firm power output with allowance for any special loads such as irrigation pumping on the project.

HEAD

B. Head is variable depending upon the reservoir content and the tailwater elevation. Before final operation studies are undertaken it will be desirable to secure a reliable tailwater curve (see Chapter 7.6 of this Volume). Preliminary studies may be based on a constant average tailwater elevation and weighted average reservoir elevation which usually is equivalent to one third drawdown or approximately 0.8 of total static head. In the interest of efficiency and economy of design it is customary to set aside the lower levels of the reservoir as dead storage so that the active drawdown of the reservoir will not exceed 0.6 of the maximum turbine head.

EFFICIENCY

C. Plant efficiency has a considerable range depending upon how near the operating conditions approach these assumed in design. Maximum turbine efficiency under ideal conditions may exceed 90 percent in well designed plants but at extremely low heads and small gate openings actual turbine efficiency may fall below 50 percent. On preliminary studies a constant overall value of 80 percent is commonly used for storage plants and 75 percent for run-of-river plants, but with very little extra labor it is possible to vary the efficiency to approximate actual performance curves. Realizable values of efficiencies which can normally be attained under actual conditions should be used, taking into consideration the proper plan of coordinated power operation. If, instead of actual realizable efficiencies, too high values are used, the estimated electrical output cannot be obtained. Conversely, if too low values are used the potential electrical output may be underestimated and the project feasibility will be adversely affected or the required average rate for electrical energy will be set higher than really necessary.

HYDRAULIC CAPACITY

D. As head and efficiency decline, the water requirement for power increases until it reaches the full discharge capacity of the turbines fixed by their design and by the dead storage level as an economic limit. This represents the maximum water requirement for power at normal load. Under generator overload conditions above rated head the turbines are operated at larger gate openings than required at normal load, and consequently greater discharge, but these conditions are not assumed in water supply studies.

CHAP. 4.3 NAVIGATION

DETERMINATION OF WATER REQUIREMENTS

.1 Water requirements for navigation depend upon channel characteristics and the depths to be guaranteed river craft at critical points. The determination of water requirements is made by the Corps of Engineers, Department of the Army, from a consideration of the channel and traffic requirements. Plans for navigation improvement are frequently authorized by Congressional Rivers and Harbors Acts or as a part of multiple-purpose projects. In many cases the upper limit of navigation is far downstream from the point being investigated by the Bureau of Reclamation and the discharges corresponding to the specified depths are affected by intermediate inflows. The amount of water required by navigation is then that necessary to supplement the flow at the control point during the navigation season. Assurance of continued availability of water for navigation purposes is best achieved where development and operation can be carried out on a basin basis with complete coordination of operations on all tributaries. There is no consumptive use of the water in navigation other than evaporation but water released to satisfy navigation requirements is usually lost to the ocean and unavailable for beneficial consumptive uses. Inasmuch as navigation is generally confined to the lower reaches of the streams and much irrigation is in the upper reaches, the two uses are frequently in conflict. Where physical conditions of channel and water supply cannot meet traffic requirements with channel improvement alone it is necessary to provide dams and locks. If navigation development under free flow conditions is precluded by irrigation development, it may sometimes be made possible by canalizing the rivers to conserve water.

DEMAND ON STORAGE

.2 Where the discharge required for navigation exceeds the natural flow of the stream it must be supplied from a storage allocation. The releases required must be ascertained from a daily study with proper allowance for time of travel lag.

OPERATING SEASON

.3 In northern locations navigation is adversely affected by ice and may be abandoned entirely for 2 to 4 months during the winter. During such periods there is no demand and water ordinarily released for navigation may be stored except for releases to maintain fish life and to insure sanitary conditions.

SHORTAGES

.4 Although because of its constitutional importance, navigation has been considered to have preeminence over other uses of streams, recognition was given by the Congress in the Flood Control Acts of 1944 and 1946, and in the Rivers and Harbors Act of March 2, 1945, to the predominent importance of other uses on streams affecting the states lying wholly or in part west of the 98th meridian.

CHAP. 4.4 MUNICIPAL, DOMESTIC, AND INDUSTRIAL USE

SCOPE OF CHAPTER

.1 Water requirements for municipal, domestic, and industrial use are ordinarily supplied under water rights obtained by the municipalities or individuals concerned. Growth of the cities together with the occurrence of years of below normal rainfall has made it necessary for many cities to seek supplemental supplies. In many localities these requirements may be supplied most advantageously by multiple-use projects. This chapter considers only the provision of total requirements without consideration of special problems such as rates of flow for fire fighting or design of distribution systems.

SUPPLIES FROM RECLAMATION PROJECTS

.2 The determination of the amount of water needed is usually obtained from the city engineer or consulting engineer retained by the town or city; but the Regional Director should be prepared to make a recommendation as to the sufficiency of the amount of water specified by the municipality. Estimates of requirement are usually based on forecasts of population and industrial growth 40 or 50 years ahead. Section 9(c) of the Reclamation Project Act of 1939 (53 Stat. 1187) forbids the making of any contract for a municipal water supply unless, in the judgment of the Secretary of the Interior, that contract "will not impair the efficiency of the project for irrigation purposes." In most instances the Bureau delivers raw water to the city and the city is responsible for treatment and distribution. Usually the city furnishes its own regulatory storage so that delivery can be made from the project canals operated during the irrigation season. This storage provides not only for the daily peak but also for periods when the canal is out of service for maintenance and repairs. In other instances the city provides its own mains from a Bureau reservoir, or if storage is not available relies upon well water supplies during the nonirrigation season.

URBAN

.3 The amount of water required varies with many factors including size of the city and character of the population, number and type of industries, climate, pressure maintained in the system, and extent of meters in use. Usually the cities applying to the Bureau of Reclamation need supplemental or replacement supplies and the amount of the demand based on past service is known. The character, amount, and distribution of the requirements for various purposes should be investigated in detail for each case individually. For new municipal developments, including construction camps and towns for large projects, estimates can be made best by reference to nearby communities of similar size and character. Usual values for average requirements for all purposes throughout the year for metered systems in the Western States range from 100 to 250 gallons per day per capita. Unmetered systems usually show more extravagant use and may average as high as 300 gallons per day per capita. The maximum monthly and daily demands average about 125 percent and 200 percent of their respective averages. The monthly distribution of demand should be based on a consideration of past records in the community revised to conform with anticipated future conditions.

RURAL

.4 The practice of supplying domestic requirements through irrigation canals and distribution systems has been followed on many projects but it is wasteful of water and adds to the seepage problems during the nonirrigation season, especially where canals are allowed to divert continuously instead of storing water in cisterns and farm stock ponds periodically. Consideration is being given in some regions to supplying farm domestic requirements through piped systems to avoid this waste. Water requirements for the farm population generally averages somewhat less than for towns because of the absence of public and manufacturing uses and use of other supplies for lawn irrigation, if any. A part of this requirement is offset by such uses as milk cooling and washing of equipment. In lieu of better data, an average per capita use of 100 gallons per day, exclusive of livestock requirements, is suggested with a monthly distribution similar to that of urban areas.

LIVESTOCK

.5 Consumption of water by livestock is a large part of the rural domestic water requirement. Following are average daily requirements for farm animals:

Horses and mules	12 gallons

Dairy cows	13 gallons
Beef cows	1-1.5 gallons per cwt.
Beef steers on feed lot	10 gallons
Dry cows	3 gallons
Calves	1-3 gallons
Sheep	.25-1.5 gallons
Pigs after weaning	1.5 gallons per cwt.
Hogs (fattening)	5 gallons per cwt.

CONSUMPTION .6 The values given in this chapter are popularly known as "consumption" but a considerable part of the urban water released through taps finds its way into sewers and eventually back into some stream and thus should, more properly, be called "demand." Actual consumptive use by most towns and small cities is comparable to that by cultivated land on an area basis. If there are large industrial uses for steam production or cooling water where evaporation loss is high the actual consumptive use is increased. Consumptive use depends to a considerable extent on the use for lawn irrigation or for maintaining ponds and lakes and will be relatively higher in arid regions than in more humid ones. Special problems concerning municipal, domestic, and industrial water use are discussed in Part 3 of Volume VII.

.1 Sewage is the return flow from water used for domestic and industrial purposes. It is waste water carrying waste products of all kinds--animal, vegetable, and mineral--dumped conveniently into streams for elimination. The waste products are in various degrees of decomposition and would create local nuisances if not removed. The streams offer the easiest means of disposal as they furnish not only transportation but dilution, dissolution, and, ultimately, complete oxidation. DEFINITION OF SEWAGE

.2 Increasing concentration of population and growth of industrial development along streams have increased the sanitary burden placed upon them. Increasing consumptive uses have decreased their capacities to carry the burden. The natural result is that some streams, once clear and pure, inviting the fisherman and nature lover, have become fouled with sludge and sewage fungi, objectionable to smell, devoid of fish, and even a health menace. In short, they have become polluted. Aroused public sentiment has demanded in many cases that streamflow be maintained sufficiently great to prevent or abate pollution, a demand which is backed up by statutory requirement in some states. STREAM POLLUTION

.3 There is a popular misconception that a running stream purifies itself in a short distance. This is true only to the extent that chemical reactions between substances in solution in the stream produce more stable or inert compounds. By far the most important of these chemical reactions in abating pollution is the oxidation of organic materials by the oxygen dissolved in the water, aided by bacteria. This oxidation is a relatively slow process. OXIDATION PROCESS

.4 Running water normally contains oxygen in solution. The amount varies with the temperature and condition of the water. The saturation content at 32° F is 14.62 ppm; at 68° F, 9.17 ppm; decreasing with increase in temperature. Mountain streams subject to frequent aeration by cascades and falls normally carry in excess of 9 ppm, the amount being greatest in winter, both because of lower temperature and smaller amounts of organic matter carried at that time. As mountain streams reach the lower valleys and plains the water becomes warmer and some oxygen is lost. A part is consumed by the respiration of fish and lower forms of aquatic life and by the transpiration of aquatic plants, such as the algae, although some oxygen is restored by these plants through photosynthesis during sunlight hours. Oxidation of organic materials during their decomposition further depletes the supply of dissolved oxygen. As the streams increase in size and temperature and decrease in velocity there are fewer opportunities for recharge and the oxygen content may become quite low or disappear entirely in badly polluted sections. When the dissolved oxygen content is lower than 1 ppm, odors generally become offensive. The tolerance of fish to pollution, both with respect to the addition of toxic substances and the removal of oxygen, varies widely with the species. Game fish, especially trout, are sensitive to pollution. They do not thrive in water with a dissolved oxygen content less than about 5 parts of dissolved oxygen per million. Rough fishes, such as carp, which obtain some oxygen from the air, can survive at lower concentrations. Advice on fish requirements will generally be included in reports by the Fish and Wildlife Service. DISSOLVED OXYGEN CONTENT

.5 This diminution in dissolved oxygen to satisfy the biochemical oxygen demand continues until a stable condition of the decomposing material is reached, usually requiring 100 days or more. The process is most active in its early stages, and the determination of the demand during the first 5 or 10 days is usually sufficient in most sanitary surveys. The determination of biochemical oxygen demand (B.O.D.) is made by determining the difference in dissolved oxygen content (D.O.) of a fresh sample and one allowed to incubate at constant temperature for the time desired. The determinations are usually made as a part of a sanitary survey, using the standard methods of water analysis approved by the American Public Health Association. The relative stability of sewage in terms of elapsed time is given by the empirical formula based on incubation at 68° F. BIOLOGICAL OXYGEN DEMAND

$$\star S = 100\,(1 - 0.794^{t})\star$$

where

S = relative stability in percent

t = elapsed time in days.

From this formula and the biochemical oxygen demand for 5 days, it is possible to estimate the demand for other periods of time. ★The formula for temperatures other than 68° F will, of course, be different.★

WATER REQUIREMENT

.6 From a consideration of the dissolved oxygen content, biochemical oxygen demand, discharge, and velocity (measuring elapsed time), it is possible to compute water requirements for pollution abatement so far as oxidation ★or dilution are★ concerned. The standards of bearable pollution are ill defined by the courts and determinations of standards are apt to be based on relative conditions rather than exactly defined. In most cases the requirement will be set up by a local group or state agency following a sanitary survey of the river by the state Board of Health, state college engineering experiment station, ★the Public Health Service,★ or other interested group. They will anticipate the discharge necessary to maintain sanitary conditions at critical points below cities or industrial plants as canneries or paper mills which place a high oxygen demand on the stream. ★Once the volume of water and its distribution throughout the year are known, the water requirements can be fitted into the general water supply studies or reservoir operation studies as readily as can any other type of requirement. Discussions of sanitary problems and sanitary surveys are also included in Part 4 of Volume VII.★

CHAP. 4.6 SALINITY CONTROL

.1 Salinity control may be a vital part of a reclamation project since water too high in salt content is not suitable for consumptive use by plants, animals, or humans, and may materially reduce the productive capacity of the land. Salinity control, as it affects water requirements, generally takes one of three general forms: dilution, leaching, or repulsion of saline intrusions. Drainage of lands through gravity drains or through pumping is a means of salinity control, but only as an instrument of leaching, or of removing the cause of salt concentration. While the problem of salts in the water available to a project or in the soils will usually be the one of primary interest, the problem of control of the salts in the downstream return flow may be of importance because of the necessity to maintain a water supply of satisfactory quality for downstream users. The problem of salinity control is closely allied to the quality of water, which is discussed in Chapter 2.4 of this Volume. Other features are discussed under irrigation requirements in Chapter 4.1. Land drainage is discussed in Part 10, Volume VII. GENERAL

.2 Where there is a source of fresh water to add to the saline water it is relatively simple to dilute the solution to a point that will not be harmful. This principle may be applied either to the source of supply for a project or to the return flow from it. It may be necessary to improve the quality of either, in order to meet the requirements of the uses to which it will be put. One of the most common methods in actual use is the storage of relatively salt-free flood flows for later addition to the more saline water of the low-flow periods. Another is the importation of water from another basin in order to accomplish the dilution. If the concentration of salts is the limiting factor, it is quite easy to compute the amount of water required for dilution by the following equation: DILUTION

$$Q_d = \frac{S_r Q_r - S_s Q_s}{S_d} \quad \text{or,}$$

$$Q_d = \frac{Q_s (S_s - S_r)}{(S_r - S_d)}$$

where

Q_d = discharge of additional water required for dilution

Q_s = discharge of salty water (before dilution)

Q_r = discharge of resulting flow = $(Q_d + Q_s)$

S_d = salinity of dilution water (Q_d)

S_s = salinity of salty water before dilution (Q_s)

S_r = salinity of resulting water after dilution (Q_r).

If the chemical composition (★★★ sodium) is the limiting factor, the problem is much more complex, the composition of both waters must be considered, as well as that of the lands to be irrigated. See Chapter 2.4, Quality of Water. The return flow waters from a project may be diluted by over-irrigation or by leaving surplus water in the streams to mingle with the return flow at or below the point of return. Overirrigation may cause excessive leaching and water-logging of the soil, and should be avoided wherever practical. This practice may, however, be required to protect the quality of ground water for direct use or to dilute the return flow water when it does not return to the surface at a point where it can be combined with water released to the stream.

.3 The leaching of salts falls into two distinct problems; (1) the water required initially to leach out soluble salts present in the soil when reclamation by irrigation or drainage or both begins, and (2) the excess water required to LEACHING

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prevent accumulation in the soil of soluble salts retained from the irrigation water consumed.

Initial Leaching

A. During the initial stages of the project operation it may be necessary to remove surplus salts in or on the surface of the soil in order to prepare the land for agricultural use. This practice rarely adds to the project water requirement as it usually can be performed with the normal supply available from lands not yet under irrigation. Even when it cannot be so met, it is not a continuing use and has no bearing upon the long-time water requirements. Initial leaching is normally accomplished by allowing water to percolate downward through the soil in sufficient quantity to carry off the surplus salts. This practice requires adequate drainage to carry away the large quantities of water required. In some localities where excessive quantities of salt are present on the surface, it is removed by the application of large volumes of water over short periods of time in order to flush away the salt with a minimum of percolation of salty water into the ground.

Prevention Of Salt Accumulation

B. The soluble salts contained in that portion of the irrigation water, which is incorporated into the plant tissues, transpired by the growing crop, or evaporated, are left in the soil of the root zone or on its surface. Unless these salts are leached out they accumulate and eventually become sufficiently concentrated to reduce or prevent crop growth. Normally, the deep percolation losses incident to irrigation are sufficient to leach out these residual salts. Likewise, in areas having considerable nongrowing season precipitation, the percolation of excess rainfall will provide the necessary leaching. However, under some conditions of high salinity irrigation water and relatively low percolation losses, it becomes necessary to provide additional water, over that required for plant growth and normal losses, in order to carry away the concentrated salts. As long as the application of water is sufficient to prevent the soil solution from becoming too saline before additional applications are made, the existing soil solution will be displaced almost completely, provided there is adequate drainage. Theoretically, the minimum amount of water required to maintain the salt content of the soil constant would be computed by the following equation:

$$Q_f = \frac{Q_c S_r}{S_r - S_f}$$

Expressed as a ratio of water requirements (farm delivery) to consumptive use, this becomes:

$$\text{Ratio } \frac{(Q_f)}{(Q_c)} = \frac{S_r}{S_r - S_f}$$

where

Q_f = quantity of water required (farm delivery)

Q_c = quantity of water consumed (consumptive use)

S_f = salinity of the water supply

S_r = salinity of the soil (or of return flow water).

Because it is impossible to spread water uniformly, and the soil permeability and the salt content of both soil and water are not uniform, more water must be applied than is indicated by the above equation. The precipitation not required for nongrowing season consumptive use may provide some such excess application. That portion of the precipitation which runs off cannot be considered as effective for salinity control. Theoretically, the salinity of the water supply (S_f) in the formula should be

reduced to allow for the fact that rain water contains no salt. However, such adjustment is a needless refinement in view of the above-mentioned reasons for supplying more water than computed by the theoretical equation, except where rainfall provides a substantial portion of the total water requirement.

4 Along coastal areas there is a tendency for salt water to intrude into streams or aquifers, if pumping from the aquifers pulls the water level down to a point below mean sea level. There is also a tendency for intrusion through the mixing of salt and fresh water or diffusion of salt into the fresh water. REPULSION

A. Fresh water has a specific gravity lower than that of salty water and will tend to float on the salty water, when there is no mechanical mixing of the two, with a zone of mixed water between the two layers. By maintaining the level of fresh water higher than that of the salty water, it is likely that the salty water will be repulsed. The height of a column of fresh water which will be supported in equilibrium by salt water is determined by the ratio of the specific gravities of the two waters and may be computed by the formula: Ground-water Repulsion

$$d = \frac{h}{g - 1}$$

where

g = specific gravity of the salt water, and (g - 1) is the difference between the specific gravity of salt and fresh waters

d = depth of column of fresh water below level of salt water

h = height of water table above level of salt water.

The higher water level will, of course, maintain a flow of water through the ground toward the sea. The amount of water required to maintain the height of the water column will depend upon slope of the water table or piezometric surface and the materials in which the ground water lies. The problem is, of course, similar to that of any ground-water movement. Some pertinent material is included in Water Supply Paper 494, "Outline of Ground-Water Hydrology." Water Supply Paper 537 discusses the problems of ground water in coastal areas, and, while it is directed specifically to the conditions in Connecticut, contains considerable information of value to the hydrologist who encounters this problem.

(1) If an irrigation development is planned for an area where no encroachment of salt water has taken place, the recharge to the ground-water reservoir over a long period must be not less than the amount pumped or otherwise discharged from the reservoir, in order to prevent the intrusion of salt water.

(2) In areas where encroachment has already taken place it may be necessary to reduce pumping operations or to effect artificial recharge to such an extent that the saline water will be repulsed. Theoretically, it is only necessary to maintain the level of fresh water above mean sea level in order to repel the saline water. This theory provides a negligible thickness of fresh water and discounts any mixing of fresh or salt waters and any diffusion of salt from sea water into the fresh water. By maintaining a head of fresh water ("h") as computed by the above equation (Subparagraph 4.6.4A), a usable depth of water may be maintained. This equation, however, does not provide for the action of tides or of variations in atmospheric pressure, both of which speed up the mixing tendencies. For practical purposes, in addition to "h" in the equation, at least a few feet of head of fresh water should be maintained above the level of normal high tide, in order to effect a more rapid repulsion of the saline water, which is at best a slow process. (The head so provided will, of course, be a sloping surface toward the coast line.)

(3) Occasionally water bearing formations containing highly mineralized water may be found overlying formations of fresh water and the two aquifers separated by a relatively impervious layer of silt or clay. If wells are used to pump the fresh water, care must be taken to seal off the saline water, not only by the use of a watertight casing, but by effecting a seal between the outside of the casing and the impervious formation. Obviously if the position of the saline and fresh water bearing materials were reversed, well casings should be seated in the impervious formations above the saline water.

Surface Repulsion

B. Where streams discharge into the ocean or into saline lakes, there is a tendency for salt water to work its way upstream. Tides cause a fluctuation of the line of demarcation and encourage mixing. The difference in density causes the fresh water to overrun the salt water so that, while the surface may be fresh, the water underneath may be brackish and unfit for plant or animal use. The most common method of alleviating this condition is by maintaining an adequate flow of fresh water. In streams having great variations of flow it may be desirable to provide reservoir storage so that water may be released during low-flow periods. The determination of the amount of water required to repulse the salt-water intrusion may be relatively easy where a single channel is present and there is little tidal flow, or it may be very complicated in delta areas. By hydraulic computations similar to those for a tailwater curve (see Chapter 7.6, Volume IV) it may be practical to compute the water flow required to maintain a slope in the water surface sufficient to repel all salt water. However, model tests may provide the only satisfactory solution to the problem.

Another method is to construct a salt-water barrier, or dam, to prevent the entrance of the salt water. Where navigation is present it is, of course, necessary to provide locks or a passageway for vessels, and usually facilities for the passage of fish should be provided. The water required with a barrier will be dependent upon the specific design of the works through which water may pass. When an open passageway is allowed for the passage of vessels, the flow must be adequate to maintain an appreciable velocity through the opening at all times. Where locks are utilized, less water will be required, but it must be sufficient to meet the requirements for lockage, spills over the barrier during periods of high discharge, evaporation from the pool above the barrier, leakage through the dam, and flow through fishways. The water level on the fresh-water side of the barrier should be slightly higher than that on the salt-water side in order to prevent the leakage of salt water into the fresh-water basin. In computing the water for lockage of vessels it is necessary to allow some discharge for flushing the salt water out of the locks. On account of density differences, when vessels enter from the salt-water side, salt water also enters and lies on the bottom. From there it flows into the fresh-water basin when the gates are opened. The specific design of the lock and the use or nonuse of a salt-water trap upstream from the lock have a strong bearing upon the water requirement. With some barriers it is impractical to prevent all entrance of salt water, so that an allowance must be made for the fresh water required to dilute this salt water to the desired limit.

CHAP. 4.7 FISH AND WILDLIFE

GENERAL

.1 The general policies and procedures relating to fish and wildlife conservation are discussed in Part 8 of Volume VII, Associated Multiple Functions. This chapter deals with water requirements for fish and wildlife purposes. For beaver, muskrats, and similar aquatic or semiaquatic animals the problem is very similar to that for fish in that sufficient flow must be maintained to meet their needs. For other animals the amount of water that is consumed is small and generally will have little bearing on the problem of water requirements for a project.

STREAMS

.2 The minimum flow needed in a stream to preserve the fish and to maintain whatever wildlife may be dependent upon it depends upon the character of the stream and the type of fish. The advice of local game authorities, state fish and game commissions, and the Fish and Wildlife Service should be sought in determining the proper flow for this purpose. It is frequently found that the proper minimum release for fish and wildlife purposes is approximately the same as the minimum recorded flow of the stream.

RESERVOIRS

.3 For fish and wildlife purposes, the most desirable reservoir is one which has a constant water-surface elevation. Since this is not practical for other storage uses, it is necessary to operate the reservoir so as to provide the optimum benefit to both wildlife interests and to water conservation interests. A reservoir with no dead storage may be a liability to fish, which tend to leave the stream and go into the reservoir during high storage periods and are stranded in the empty reservoir when the water is withdrawn.

FISH-LADDERS

.4 Water passed through fish-ladders may generally be utilized to meet other downstream requirements. It is not practical to state here the method of computing the amount of water required to operate a fish-ladder, as the size and type of ladder, the number of fish to be passed, and the period of time during which it must be operated, will dictate the amount of water that must be released. It will be necessary to consider each installation separately. When establishing the water requirement for this purpose, both the designers and the Fish and Wildlife Service should be consulted.

WATER RIGHTS

.5 The relation of water rights to releases for fish and wildlife purposes may have a strong bearing upon the studies of water requirements for these purposes. In some states the water laws do not make any provision for water rights for these purposes, which may make it impossible to provide water for fish and wildlife benefits. Even if releases were made for such purposes, downstream water users might be permitted to divert the flow, thereby destroying its benefit for the purpose and affording a benefit from the project to persons not participating in its repayment.

CHAP. 5.1 INTRODUCTION

GENERAL

.1 Project water supply operation studies are made to visualize the manner in which the project will work. In operation studies various assumptions as to water supply and the demands upon it are compared under anticipated operating conditions. Basically, operation studies are extremely simple. They are simply an accounting system devised to keep track of water. Once supplied with the amount of water available for use, the demands for its use and a physical plan, the operator need only account for all withdrawals and returns from the water available. In its final form the operation study is a picture of the project in action based upon run-off conditions experienced in the past. The final operation study is usually preceded by trial studies which are made for the purpose of analyzing the various project elements. Assembly of much factual information is essential prior to starting an operation study. The amount and reliability of the information needed will be dependent upon the purpose of the study, and the use to which the results will be put. Parts 1 to 4 of this Volume will provide guidance in assembling the information needed for operation studies. Essential information must also be obtained as described in Volumes V, VI, VII, VIII, and other parts of the Manual. Final operations from which design data are obtained cannot be made without a complete knowledge of all elements affecting the resources being used.

PERIOD OF STUDY

.2 Studies for rough preliminary estimates are frequently made on an annual basis but studies based on monthly or daily flows are ultimately necessary. Daily studies often are necessary if diversions are contemplated without benefit of storage. The study period to be selected is necessarily partially dependent on the availability of stream-flow records and other data but should include the period of low flow which makes optimum usage of the reservoir capacity, and should extend through a period prior and subsequent to the period of low flow sufficiently long to represent a realistic cycle of operations. It may be necessary to investigate various periods of low stream-flow years as well as the most critical period of stream flow where holdover storage is involved, in order to determine the most critical period of project operation.

UNITS OF COMPUTATIONS

.3 Units of electrical energy are commonly expressed in terms of thousands or millions of kilowatt-hours. Volumes of water used in reservoir operation studies are usually expressed in acre-feet. It is usually permissible to round these volumes to the nearest 100 acre-feet or even 1,000 acre-feet, depending upon the quantities of water being handled and the accuracy of the result desired, always keeping in mind the practical limitations of the basic data. Accuracy of derived data should be maintained at highest levels consistent with basic information and purposes of the study.

ORGANIZATION OF STUDY

.4 Operation studies are usually set up with the elements in columns conveniently arranged with figures listed on lines opposite the months or days of the year. The number and arrangement of columns will vary with each study. Columns should be provided to allow inclusion of factors vital to the study and arranged in sequence to facilitate their use. As trial studies are made and work progresses the best arrangement and selection of columns will be evolved. It is usually desirable to summarize results of final studies in a concise manner for inclusion in a report. The arrangement of the summary will be dictated by the elements being reported on. When it is anticipated that several studies will be performed containing several columns of constant figures, considerable saving in time and accuracy will be obtained by acquiring copies of the work sheets after the constant elements have been tabulated and arranged to suit the needs of the study. Except in the simplest of operations, a large amount of paper space is ordinarily required for the studies and saving in space may be accomplished by setting up a large part of the items on auxiliary tables.

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PURPOSE OF STUDIES

.1 Reservoir storage is usually required to approach full utilization of most streams. The primary purpose of such storage is to regulate the stream so that the natural flow will equal, as nearly as possible, the rate of demand for water. The degree of regulation of streamflow which is possible or desirable with a storage reservoir can, in part, be determined through the use of reservoir operation studies. It must be recognized, however, that reservoir operation studies are closely related to other studies of the project, such as economics. Reservoir operation studies then become but one of the useful tools for examining and testing the factors which constitute the project plan.

PRINCIPAL RESERVOIR TYPES

.2 There are two general types of storage reservoirs:

A. Reservoirs located on the stream which they regulate known as "on-stream reservoirs" and generally fed by direct flow.

B. Reservoirs located away from the stream, generally known as "off-stream reservoirs," supplied principally by diversion from the main stream or other tributaries.

DIFFERENCES IN TYPES

.3 Most procedures followed for the study of "on-stream reservoirs" are applicable to "off-stream reservoirs"; however, there are certain fundamental differences. Storable inflow to off-stream reservoirs is controlled by the surplus flows in the streams at points of diversion and by the capacity of the feeder canals. Local and economic conditions will seldom permit construction of feeder canals to accommodate full river flows at diversion points, as discussed in Chapter 5.2.

RESERVOIR INFLOW

.4 Considerable discussion in other chapters of this Volume has been devoted to the assembly and estimation of operation data. Inflows to the reservoir must be determined for a sufficiently long period of time from past records of water available. Procedures to be followed in determining the reservoir inflow are discussed in Part 2. Reservoir inflow should be determined for periods of high, low, and average water supply to allow study of the reservoir under all conditions for which the project is being designed. The purposes of the project should provide guidance in selection of the study period. All historical inflow to a reservoir is commonly not available for project uses. It is necessary to adjust the inflow to reflect conditions anticipated during the life of the project. Commonly, there has been a progressive increase in upstream depletions requiring an adjustment in historical data before they can be projected to represent anticipated future conditions. It is also necessary to determine the nonstorable inflow which must be reserved for established water rights, interstate compacts, international agreements, potential and authorized projects, and any other water use for which a priority use is anticipated. A discussion of water rights may be found in Part 3.

DEMANDS ON STORAGE

.5 After the water supply available to the project has been determined, it is necessary to establish the amount and duration of the demands which can be expected to be made upon project storage. This study will also involve the determination of that portion of project demand which can be met by means other than release from storage. Some of these means may include effective rainfall, local inflow below the point of storage, pumping from ground-water storage, and re-use of return flow. Demands on storage may be for a great variety of uses to include irrigation, power production, sanitation, salinity control, navigation, fish and wildlife propagation, and municipal and domestic use. A more detailed description of these requirements may be found in Part 4.

RESERVOIR CHARACTERISTICS

.6 Prior to initiation of reservoir operation studies, it is necessary to determine various characteristics of the reservoir site such as losses expected from evaporation and seepage, losses which have occurred due to transpiration, evaporation, seepage, and other uses prior to inundation; area and capacity of the reservoir at various elevations with expected sediment disposition; bank storage to be expected, if any; and the volume, rate of infiltration, and release of such storage, and any other reservoir characteristics which should be considered in operation of the reservoir.

EVAPORATION LOSS .7 The most significant of the losses from reservoir storage is evaporation. It can seldom be neglected even for reservoirs at high altitudes and in high rainfall areas. For an existing lake of large area the increase in loss might be small; for an arid basin the increase might be considered approximately equal to the difference between the evaporation from a large free water surface and the rainfall. Except in special cases, reservoir losses by evaporation are based on an average amount and distribution. Although considerable theoretical study and experimental work has been done to determine the laws controlling evaporation and the effect of the factors involved, there is still much difference of opinion regarding this subject. Of the several methods of determining evaporation, the computation from formulae based on atmospheric elements, observations from various types of pans, and direct records from large water areas are the most commonly used. Conditions are seldom favorable for the direct determination of evaporation from large water areas; however, when evaporation has been computed for an existing body of water from detailed measurements of inflow, outflow, and precipitation, it becomes an excellent tool for estimating the probable evaporation from other reservoirs in the same vicinity. Consideration should be given to differences of climatic conditions which affect use of the evaporation data. The estimating of evaporation for a reservoir is often dependent upon records of evaporation from small pans. The rate of evaporation from different type pans varies widely, and before the records can be used in estimating it is necessary to know the ratio between the pan and free water-surface evaporations. Coefficients for reducing pan evaporations to large water surfaces have been tentatively established by experiments. The usual coefficients for the various types of pans in regular use follow:

Type of Pan	Diameter in feet	Setting	Coefficient
Weather Bureau Class A	4	Above ground	0.70
Bureau of Plant Industry	6	Set in ground	0.94
Geological Survey	3 (sq)	Floating	0.77
Weather Bureau	4	Floating	0.78
Colorado Land	3 (sq)	Set in ground	0.78

When evaporation records and reducing coefficients are available from places of observation at or near to the reservoir site, it is a comparatively easy task to estimate the probable evaporation from the reservoir, particularly if the relative climatic conditions are very nearly the same. It is usually necessary, however, to utilize evaporation data for points of observation at some distance from the reservoir and to make appropriate corrections for the reservoir evaporation by use of the primary factors which influence evaporation. These corrections can be made in various ways by using temperatures, wind velocities, humidity, and elevation as estimating tools. These are the principal factors which influence evaporation and are so interdependent that it is difficult to segregate the effects of any one. In some areas, particularly in the Rocky Mountain Region and California, the evaporation depends largely upon temperatures which decrease with an increase in elevation. Ordinarily there is a corresponding lack of records of wind velocity and humidity in areas where evaporation station records are few, which necessitates the use of mean annual temperatures as the factor to be used in estimating the evaporation from the reservoir. The estimate is frequently made by plotting monthly total evaporation against corresponding monthly mean temperatures using average values over a period of years, preferably the period used for the water supply study. This produces a loop curve which may be entered with mean monthly temperature values representing the reservoir conditions to obtain corresponding evaporation rates. For most northerly stations evaporation records do not extend through the winter months. The temperature-evaporation loop curve can be extended by judgment in a smooth curve as the basis for estimating winter evaporation, or where winter evaporation records for similar climatic conditions

can be found, even though at a distance from the reservoir site, they can be used as a guide in extending the curves for nearby stations. Unless there is an evaporation station reasonably close to the reservoir site, it is desirable to construct temperature-evaporation curves for two or three of the closest stations and estimate from them a curve to represent the reservoir considering shapes of curves as well as differences in temperatures. In the few instances where there are numerous evaporation stations it will be possible to prepare maps showing lines of equal evaporation from which monthly or annual evaporation may be interpolated. It is rarely possible to compute probable evaporation from a reservoir by use of formulae based on atmospheric elements because of the scarcity of records of these elements. Consideration should be given to the use of formulae which have been derived from a consideration of the factors influencing evaporation with the empirical coefficients necessary to reduce the results to losses from water surfaces of large areas. EVAPORATION LOSS (Cont.)

.8 Plants growing in water, such as tules, cattails, and sedges, are users of large quantities of water. River-bottom growths, such as salt cedar (tamarisk), willows, and cottonwoods, usually consume more water than an equal area in irrigated crops. The meteorological conditions influencing evaporation from water surfaces likewise affect transpiration by vegetation so that evaporation from water may, under certain conditions, be used as an index of transpiration losses. Experiments conducted in certain areas to determine the use of water by phreatophytes should be fully utilized in estimating the probable loss to be expected from a reservoir by this cause. It will be noted that even though the evaporation from the reservoir water surface decreases in total with reservoir drawdown, the losses by transpiration from plant growth continues in some amount especially in delta areas at the head of the reservoir and much of the water held in bank storage evaporates from the soil surface. Estimates of reservoir losses from an anticipated growth of plants within and immediately adjacent to a reservoir may be estimated by investigation of the several factors involved and aided by a personal knowledge of local conditions. TRANSPIRATION LOSS

.9 Thus far only the principal factors that comprise losses chargeable to a reservoir have been discussed in detail, but those losses should be modified by subtracting the prereservoir losses. The losses which existed before inundation in the form of channel losses; use by irrigated crops and native vegetation; evaporation from ponds, swamps, and lakes; and use for domestic, municipal, and industrial purposes all should be deducted from the future reservoir losses. In the case of a small reservoir the salvage from channel covered may be insignificant and may be disregarded, but it becomes an item of major importance in a reservoir that covers a large amount of channel. The consumptive use of water in the reservoir area by crops, native vegetation, etc., must usually be estimated. For rough studies involving unirrigated reservoir basins in arid areas, it is ordinarily satisfactory to assume that the present consumptive use is equal to the mean precipitation. When the factors influencing storage loss chargeable to a reservoir have been determined, it may be possible to incorporate them into a curve or family of curves similar to those shown in Illustration 1. PRERESERVOIR LOSSES

.10 Another factor contributing to reservoir loss is seepage. It is customary to consider seepage losses in the case of existing reservoirs where significant loss is known to occur or in the case of potential reservoirs where loss is anticipated. Seepage loss should be considered in most studies as uncontrolled reservoir release. Advantage should be taken of seepage losses whenever they can be put to beneficial use. The most common type of loss by seepage is probably beneath the dam through valley fill materials too deep to be cut off economically and where it is too expensive to grout or blanket with more impermeable material. Losses through pervious formations such as broken lava or cavernous limestone exposed in the reservoir basin may be even more troublesome to anticipate. Estimates of probable underflow of this type should be made by the Regional Geologist with the advice of the technical staff of the Branch of Design and Construction, using percolation test data obtained during the exploration program if available. SEEPAGE LOSS

BANK STORAGE .11 In addition to normal storage, the geology of the reservoir might permit bank storage, the magnitude and characteristics of which may be estimated. Generally, significant quantities of bank storage may occur when the formations within the reservoir area, below the normal water surface, are permeable and extensive. Examination of the reservoir site by a geologist will usually indicate when bank storage should be considered in the reservoir operation studies. If, after preliminary examination of the site, the geologist considers additional information is needed, the formations should be mapped to a suitable scale and undisturbed samples of the formations obtained by means of test pits and test drilling. These samples should be sent to the earth materials laboratory for determination of permeability and specific yield. In such instances it may be advisable to request the assistance of specialists in the Research and Geology Division, Branch of Design and Construction. Field tests may also be used in determining permeability. If, after the above tests, the transmissibility of the deposits is considered sufficient to affect the reservoir operations, the data should be assembled and submitted to the Dams Division, Branch of Design and Construction, for development of graphs showing accretions to and losses from reservoir storage under various assumed cycles of water level fluctuation in the reservoir. The development of the curves is a complex mathematical treatment, in which various assumptions approximating the true conditions must be made. Appropriate allowances may then be made by the use of these curves in the final reservoir operation studies.

SEDIMENT STORAGE .12 The normal storage of the reservoir should be further altered to allow for the deposition of sediment. All natural streams carry some sediment; and water which is impounded directly on the stream or which is diverted from such a source to be impounded elsewhere will deposit sediment in a reservoir. The procedures to be followed in the determination of the sediment deposition and disposition are discussed in Part 9 of Volume VII. Before making an operation study, it is logical to alter the area-capacity curve for sediment deposition. This alteration should be made for a sediment accumulation consistent with the sediment allocation as discussed in Paragraph 9.1.3 of Volume VII. Operations studies may be made for interim periods of sediment accumulation on reservoirs that rapidly fill with sediment where judgment has determined that the sediment allocation should be for a period of 100 years or longer. These studies will determine maximum use of storage that may be made in the early life of the reservoir.

STORAGE ALLOCATIONS .13 Having considered the water supply available to the project, the demands on storage reservoir characteristics, and storage losses, it is possible to determine the amount of storage required. It is necessary to consider the storage allocation for all uses such as irrigation, sediment control, power, and flood control. While releases from storage may serve more than one purpose, separate allocations are often required for economic reasons and for the establishment of operating criteria. In general the total reservoir storage capacity is the sum of the capacities required for uses; however, the physical limitation of the site is at times the governing factor, and in such cases additional studies are required to determine the most desirable allocations.

IRRIGATION STORAGE .14 Reservoir operation studies are required to integrate unregulated water supply and demands with reservoir characteristics to determine storage capacity needed best to serve demands for irrigation and/or other conservation purposes. Studies can be made on an annual, monthly, or daily basis. Annual studies will suffice for determining tentative information, such as approximate capacities to be considered. Monthly studies are generally adequate for most purposes, but daily studies may be required when a high degree of refinement is necessary. The study is composed essentially of inflow, demands, losses, and reservoir content, and in its simplest form is a tabular accounting of the equation inflow equals change in content (algebraic) plus losses plus demands on storage. The tabulation becomes complex as many components of these basic factors are added. Inflow to the reservoir is considered to be all water available to the reservoir after adjustments have been made for upstream uses and regulation as previously explained in this chapter. All inflow can be assumed to be taken into storage and releases made from storage for prior

rights downstream; or the inflow can be broken down into components of "storable flow" and "flow for downstream rights." Demands can be separated into "demands on storage" and "direct flow demands" to correspond with the breakdown of inflow. Such a breakdown in the study will usually provide a better understanding of the benefit of storage. Losses from the reservoir are determined as described in the foregoing paragraphs, and are appropriately applied to the study. If losses are dependent on the reservoir content it is customary that the average content for the period be used. Reservoir content is usually determined for the end of the year, month, or day--whichever period is being used in the study. It reflects the resultant change due to inflow, demands, and losses, and if the computations of the study have been correct, the reservoir content at the end of any period will equal the content at the end of the previous period, plus all inflow, minus all releases and losses. The generally accepted form of study is a sheet divided into columns, with the years, months, or days in the left-hand column followed in successive columns by inflow, demands, losses, and reservoir content. Appropriate headings should be given for each column, with any other references that would be required to make the study easily understood. In monthly studies, totals of each column should be made for each year, and in daily studies totals should be shown for at least each month. Preliminary studies of various reservoir capacities will be required in order to determine the capacity most suitable for serving the demands with allowable shortages. Some preliminary studies can be made by use of a mass diagram analysis, with refinements being made with trial operation studies. Graphical representations of final studies should be made as described in Chapter 5.5, and annual or monthly summary sheets should be made of monthly and daily studies respectively.

IRRIGATION STORAGE (Cont.)

.15 Reservoir storage capacity required for power production is determined by operation studies made either in combination with studies required to determine storage capacity for other purposes as previously described, or for power only. When power alone is being considered, it is desirable to transform the flow of a stream into a regulated discharge with a minimum fluctuation of the reservoir pool. Water requirements for hydropower production are discussed in Chapter 4.2. (Also see Volume VI.) Once having converted the demand for hydropower into terms of water and its priority, the treatment of this demand for water is the same as the demand for any other purpose. Preliminary estimates of storage capacity needed for this purpose can be made by mass diagram analysis. Final selection of economic capacity for power production may be made by a comparison of costs of storage with energy generation for various heights of dam. The determination of storage space in a reservoir is closely related to, and usually an integral part of, the over-all planning studies for power development.

POWER PRODUCTION STORAGE

.16 Frequently the hydrologist is called upon to make hydropower studies of a tentative nature for guidance in planning studies. Such a study requires basic data on reservoir and power plant characteristics, streamflow, and other physical planning data. A tentative operation study is made, usually on an annual basis, through a critical period of water supply to approximate reservoir capacity, energy output, and evaporation. The results of the annual study will enable a monthly study of energy output to be made. Subsequent analysis will enable refinement of the studies to the point where the firm continuous output can be determined and the storage capacity tentatively selected. (See Chapter 7.7.)

TENTATIVE POWER OPERATION STUDIES

.17 As more refined studies of power production are undertaken, refinements of basic data used are necessary. Maximum firm power output should be determined by months for various stages of development desired by conducting an operation study. Such a study will require the use of curves for gross head, and energy output per unit of water plotted against storage. Upon completion of the study a graphical presentation should be prepared showing energy output (both firm and nonfirm), and duration graphs of energy.

PRELIMINARY POWER OPERATION STUDIES

.18 When a final plan of operation has been determined, the operation study may be repeated using manufacturer's data as furnished to the Chief Engineer; final-type tail-water curves; designer's curves of outlet, turbine, and spillway discharges; and representative load curves.

FINAL POWER OPERATION STUDIES

FLOOD CONTROL STORAGE .19 Flood control storage is frequently a part of a multiple-purpose project. Flood control investigations and studies on Bureau projects are performed in consultation and cooperation with the Corps of Engineers, Department of the Army. The reservoir capacity allocated for flood control is determined by routing the reservoir design flood through the reservoir, assuming that initial water surface is at the top of the space previously determined and allocated to dead storage and conservation storage, and that releases from the reservoir during the filling of the flood control storage do not exceed safe channel capacity downstream. (See Chapter 7.1.) Some encroachment may be allowable on the flood control storage space by storage for irrigation, power, navigation, or other uses if a suitable forecast plan can be devised to allow such encroachment at times when subsequent flood control operation will not be jeopardized. The economic limit for the allocation of flood control space is determined by the relationship of benefit to cost involving flood damage studies for floods of various magnitudes. (Part 2 of Volume VII pertains to studies of flood damages.) Surcharge storage above the top of the allocated flood control space is provided to protect the structure against floods greater in magnitude than the reservoir design flood. The most economical combination of surcharge storage and spillway capacity is determined by routing the inflow spillway design flood through the reservoir, utilizing part or all of the allocated flood control storage, and conforming to flood control operating criteria for that space. (See Chapter 7.5.)

FLOOD CONTROL OPERATION STUDIES .20 Flood control operation studies are necessary for the proper planning, design, and operation of multiple-purpose Bureau of Reclamation reservoirs. They are useful in arriving at the storage allocation for flood control, in providing a sound basis for developing and testing flood control operating criteria; they make possible a reasonable evaluation of flood control benefits; and they provide a preview of what the reservoir will be able to accomplish under actual operating conditions.

FLOOD CONTROL RESPONSIBILITIES .21 Flood control as such is largely the responsibility of the Corps of Engineers, Department of the Army. However, the Bureau of Reclamation has an active interest in the allocation and utilization of flood control storage space in multiple-purpose reservoirs which it constructs and operates.

TYPES OF FLOOD CONTROL STORAGE .22 The function of flood control storage is to impound water during periods of excess runoff in order that it may be released later at nondamaging rates. The storage for flood control may include any or all of the following types:

A. Inviolate storage--every year and all year.

B. Seasonal allocations--every year on a seasonal basis.

C. Joint-use capacity--varying from year to year and based on precipitation indices, snow surveys, and other watershed conditions, but available for flood control any year as required. (Watershed conditions are generally determined by operating agency.)

Operation studies involving year-around and seasonal flood control allocations are quite orthodox and require no special discussion. Operation studies involving variable flood control allocations are, however, more complex and they will be given detailed consideration in the following paragraphs.

PARAMETER-TYPE OPERATION STUDY .23 The term "parameter operation" is commonly given to the type of operation study involving variable flood control allocations. The term is derived from the operating parameter curves which are the key feature of this type of operation. Through the use of these parameters and seasonal runoff forecasts, it is possible to anticipate the flood control space reservation which will be required to control the oncoming flood to safe channel capacity. The required capacity for flood control is provided, and the reservoir is permitted to refill at a safe rate as the flood potential is decreased. This type of operation permits optimum utilization of joint-use space at reservoirs where the bulk of the flood inflow is derived from snowmelt and where seasonal snowmelt forecasting

can be accomplished with reliable accuracy. The parameter-type operation is recommended for potential Bureau of Reclamation reservoirs for which a flood control storage allocation is to be made and for which the seasonal flood inflow is predictable.

SEASONAL RUNOFF FORECASTING

.24 The first step in the parameter-type operation study is the development of the forecasting tools. The forecasting tools are twofold. One tool is the established relation between seasonal runoff and precipitation indices, snow surveys, and other watershed conditions. This relationship can be expressed in graphical or analytical form. The procedure for developing seasonal runoff forecasts is discussed in Chapter 8.1.

DERIVATION OF PARAMETER CURVES

.25 The other forecasting tool is the so-called parameter curves, or operating chart. It provides a means for translating the seasonal runoff forecast into required flood control storage reservation, or its inverse volume, allowable reservoir storage content. The derivation of this chart is described in Appendix I to this chapter.

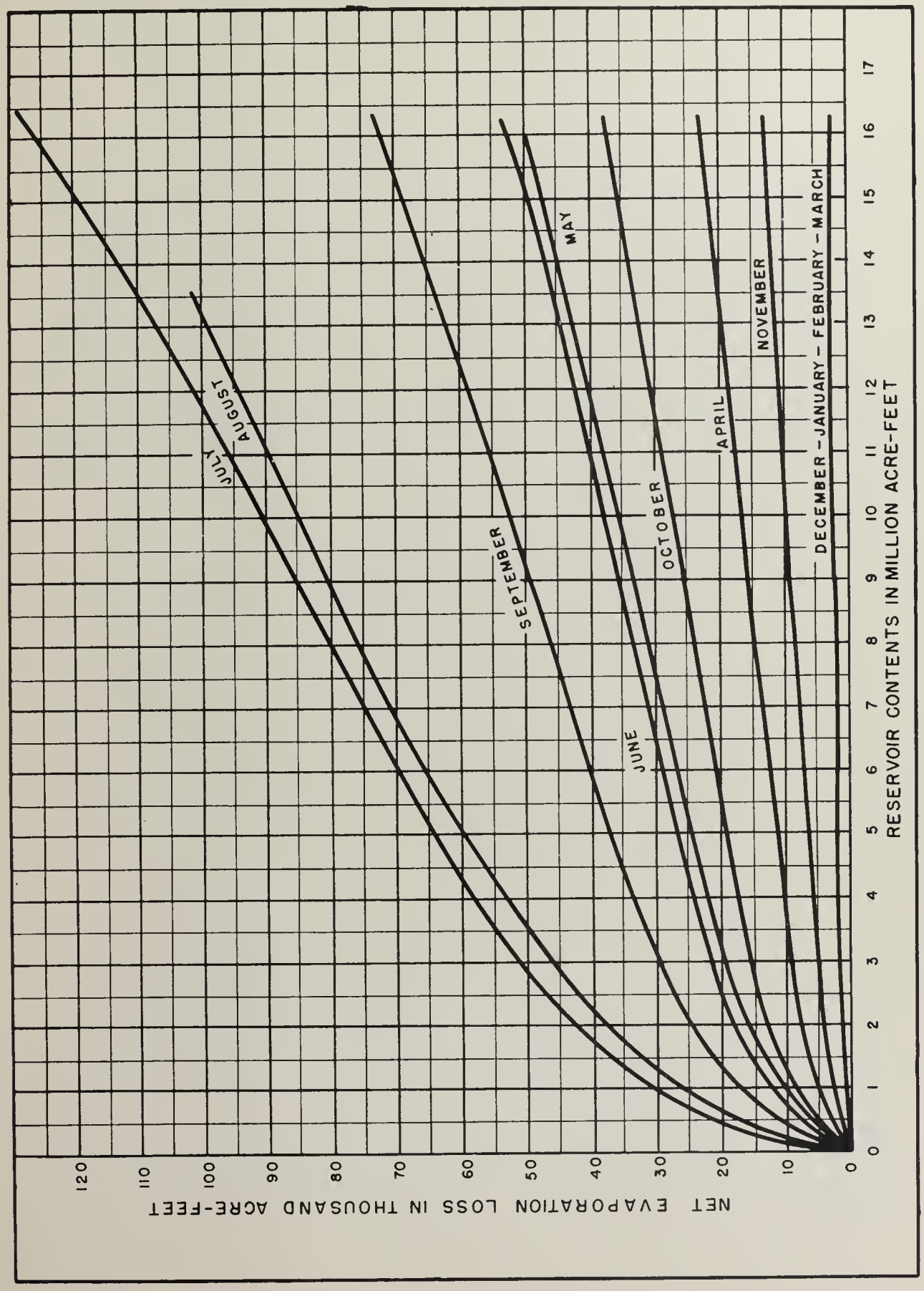
MULTIPLE-PURPOSE STORAGE

.26 Multiple-purpose projects of the Bureau of Reclamation can include the combination of any or all purposes such as irrigation; power; flood control; sedimentation control; navigation; municipal, domestic, and industrial supplies; stream pollution abatement; and others. Releases from multiple-purpose reservoirs are generally usable for more than one purpose; e.g., irrigation, navigation, flood control, power, and other purposes. The problem of determining the economical capacities for the various purposes becomes more complex as more uses are incorporated. Final solution will require several trial studies based on different capacities. The most feasible combination of uses must be evolved from operation studies based on the complete picture of the project. The inflow, the feasible physical limitation of the reservoir, irrigable acreage, energy requirements, and other conditions are frequently obvious at the beginning of the study. Preliminary mass diagram studies can be made based on these facts to determine the relations existing between inflow, draft, and storage. Refinements of these relationships must be made from the detail operation studies, which can be made in the same manner as the operation studies for the individual features, except that consideration must be given to the multiple uses of all releases from the reservoir.

ENGINEERING FEASIBILITY OF PROJECT

.27 Determination of the engineering feasibility of a storage project becomes more involved as the uses to be made of the storage increase. Feasibility of the various phases of the project are considered from the first tentative study through the final operation study. A balancing of supply and demands for various uses is often necessary in determining the cost and benefits to be assigned to each use made of storage. In the final determination of project feasibility, consideration must be given to the nonreimbursable costs and benefits assigned to various storage utilizations. The statement regarding allowable limits of shortage, Paragraph 5.2.5, is also applicable in the case of storage projects. See Part 3, Project Selection, Volume III, for criteria used in selecting projects.

EVAPORATION LOSSES



CHAP. 5.3 RESERVOIR OPERATION STUDIES
APPENDIX I SAMPLE COMPUTATIONS--PARAMETER CURVE OPERATION

HISTORICAL FLOOD ANALYSIS

.1 Historical floods are analyzed in order to determine the storage space that would be required for flood control if there were complete knowledge of the forthcoming flood event. In order to conduct these flood analysis studies it is necessary to have available the following basic data:

A. Safe channel capacity at critical downstream point.

B. Joint-use capacity.

C. Daily discharges for significant floods of record.

Each significant flood is analyzed to determine the storage space required at various times to control the flood, insofar as possible, to safe channel capacity. The procedure can be illustrated by a hypothetical example. Suppose that it is desired to limit flows at the critical downstream point to a safe channel capacity of 2,000 cfs. Joint-use space amounting to 60,000 acre-feet will be made available as required in order to accomplish this objective. Assuming complete foreknowledge of the flood event, the analysis would be as shown in Example 1.

PLOTTING OF HISTORICAL FLOOD OPERATION

.2 Having analyzed the storage requirements for this flood under ideal operating conditions (complete foresight), the next step is to plot the operation data on coordinate paper. For the above example, the data would be plotted in the following manner:

(1,000-acre-foot units)

Date (abscissa)	Flood control space requirement (ordinate)	Allowable reservoir content (ordinate)	Flood volume remaining from given date to July 31 (3rd variable)
April 26	0	60.0	298.9
May 1	13.4	46.6	292.3
May 16	25.6	34.4	244.5
May 20	30.1	29.9	233.0
June 1	15.6	44.4	170.5
June 16	1.9	58.1	96.8
June 19	0	60.0	82.9

After plotting this one flood, every other significant flood of record is similarly analyzed and plotted. Care is taken to include minor floods which occur either early or late in the flood season, as these minor floods might prove valuable as control points. The complete plotting is normally a maze of intersecting lines, supported by third-variable plottings of remaining runoff volumes. All operational plottings begin and end with the joint-use flood control space full.

THE ENVELOPING PROCEDURE

.3 After the plotting is completed, enveloping parameters are drawn. These parameters are the substance of the operation chart, Example 2. The manner in which they are drawn is indicated in the diagram, Example 3. The objective with respect to flood control is to construct curves, or parameters, which envelop all of the runoff volumes plotted as third variables. As an illustration, the parameter in Example 2 designated 2.0 (200,000 acre-feet) envelops, or falls below, all third-variable plottings less than 200,000 acre-feet.

TESTING & ADJUSTMENT OF PARAMETERS

.4 Usually considerable testing and adjustment of the enveloping parameters is necessary before the final curves, Example 2, can be derived. Testing is accomplished by running trial operation studies for critical flood or drought

periods, using runoff forecasts and the trial operation chart. Adjustment consists of smoothing, equalizing the spacing for continuity, and seeking to make upward adjustments in the parameters. This adjustment usually benefits irrigation interests, and care should be taken to adjust the parameters until the reservoir content which the parameters indicate as allowable on any given date is actually the maximum content permitted by the enveloping criteria.

USE OF PARAMETER CURVES .5 The end product of the derivation of the parameter curves is the operation chart, Example 2. Use of this chart can be illustrated by an example. Suppose that on May 1, the runoff forecast for the period May 1 to July 31 is 300,000 acre-feet. The chart is entered on May 1 with the runoff forecast of 300,000 acre-feet (3.0 in units of 100,000 acre-feet), and the intersection of these two lines indicates that there should be a flood control reservation of 25,000 acre-feet, or a maximum reservoir content of 35,000 acre-feet, if the remaining snowmelt inflow is to be controlled to channel capacity. This assumes reasonable forecast accuracy, and also the fact that the timing of the forthcoming snowmelt inflow will not be more severe than is indicated by the envelopment of all recorded flood events.

EXAMPLE OF PARAMETER-TYPE OPERATION STUDY .6 The first step in the parameter-type operation study . . . the development of the forecasting tools . . . has been explained in detail. The next step is to indicate how these tools are used in an actual operation study. This can be done by presenting a hypothetical example of a parameter-type operation study. For the hypothetical example, let it be assumed that the following data are available:

A. Joint-use capacity: 60,000 acre-feet.

B. Safe channel capacity: 2,000 cfs.

C. Hold-over storage: 51,300 acre-feet.

D. Daily inflows to reservoir.

E. Daily flows at critical downstream point.

F. Required monthly irrigation releases.

G. The average date on which flows at critical downstream point exceed 2,000 cfs: May 20.

H. Forecasts of runoff at critical downstream point from first of month to July 31, as follows:

Date of Forecast	Forecast (acre-feet)	Subsequently measured (acre-feet)
March 1	250,000	234,000
April 1	244,400	230,100
May 1	242,200	207,100
June 1	124,500	127,200

OPERATING PROBLEM .7 The problem is to operate the reservoir for the given year, using runoff forecasts (see Chapter 8.1) and the parameter-type operating curves, Example 2. The manner in which this has been accomplished is indicated in Examples 4 and 5, and in the following discussion.

FORECAST .8 Referring to Example 4, the small inflow during January and February can be stored. On March 1, when the first runoff forecast is available, it is desirable to look ahead and anticipate the maximum drawdown that will be required for flood control. If the forecasts are perfect, maximum drawdown should occur

FORECAST (Cont.)

on the day when storage of excess flood flows begins, which is assumed to be on or about May 20. Since the forecast is likely to be imperfect, this "looking ahead" should assume that the timing of snowmelt runoff is the most critical of record. This assumption leads to the use of minimum runoff record in the computation of runoff remaining after May 20. The computation is made as follows:

	Acre-feet
Forecast on March 1 of March 1-July 31 runoff	250,000
Minus minimum runoff of record, March 1-May 20	30,300
Prognostic forecast on March 1 of May 20-July 31 runoff	219,700

OPERATIONAL OBJECTIVE ON MARCH 1

.9 The runoff forecast of 219,200 acre-feet is translated into allowable reservoir content on May 20, by use of the parameter curves, Example 2. The curves are entered along the May 20 date line with the forecast of 219,200 acre-feet (2.20 in 100 thousand acre-foot units) and read-off the allowable reservoir content of 21,500 acre-feet. The operational objective on March 1 is to bring the reservoir to a content of 21,500 acre-feet on May 20. However, the reservoir should be drawn down only a proportionate amount by April 1 since a new, and presumably more accurate, runoff forecast will be available at that time. To determine the proportionate drawdown during March, place a straightedge on the chart, Example 2, connecting the points defined by the actual content of 52,300 acre-feet on March 1 and 21,500 acre-feet content on May 20. Intersection of this line with the April 1 date line indicates that the reservoir should be drawn down to 40,500 acre-feet during March.

OPERATIONAL OBJECTIVES ON APRIL 1 & MAY 1

.10 On April 1, when the new forecast is available, the allowable content is re-estimated. The proportionate drawdown during April is determined, and the reservoir is drawn down during April to the required content. On May 1, another forecast is available, and the allowable content on May 20 is re-estimated. In order to bring the reservoir to the allowable content on the day when storage begins, it is usually necessary to put the operation study on a daily basis during May and June. The daily operation is shown in Example 5.

DAILY OPERATION MAY 1 TO 20

.11 Referring to the daily operation table, the operational objective on May 1 is to draw down the reservoir to content 20,000 acre-feet by May 20. When this is accomplished on May 4, the allowable reservoir content on May 20 is again re-estimated. The experienced runoff from May 1 to 4 is subtracted from the May 1 runoff forecast. The minimum runoff of record from May 4 to 20 is also subtracted. The resultant May 20 forecast is translated into allowable content by means of the parameter curves, and it is found that the objective of 20,000 acre-feet is still valid. Two days later, the allowable content on May 20 is again estimated, and it is found that the allowable content is 21,000 acre-feet. The reservoir is filled to 21,000 acre-feet, and the allowable May 20 content is then re-estimated to be 23,000 acre-feet.

DAILY OPERATION MAY 20 TO 31

.12 The process of filling the reservoir to the allowable content on May 20, re-estimating, and then filling to the new allowable content is repeated until May 20. Filling is possible because experienced runoff in May was greater than the minimum May runoff of record. The critical date of May 20 is finally reached, and flows do not exceed 2,000 cfs at the critical downstream point. The operation proceeds cautiously day by day after May 20, until May 25, when flows actually begin to exceed 2,000 cfs. From May 25 to 31 inflow is stored to the extent necessary to limit downstream flow to safe channel capacity (2,000 cfs or 4,000 acre-feet per day).

DAILY INFLOW IN JUNE

.13 On June 1, a new and presumably more reliable estimate of the remaining flood runoff can be made. This estimate indicates that there is less runoff remaining than had been indicated by the May 1 forecast. As of June 1, with an anticipated runoff volume of 124,500 acre-feet remaining, past experience as incorporated

into the parameter curves, Example 2, indicates that a reservoir content of 44,000 acre-feet on June 1 would permit control of this anticipated runoff to safe channel capacity. Accordingly, the reservoir is filled to content 44,000 acre-feet, and a re-estimation is made of allowable content as of that date (June 11). It is found that the content could be 54,500 acre-feet on June 11. The forecasting and filling process is repeated until the reservoir fills on June 29.

OPERATION JULY 31 TO DEC. 31 .14 The operation for the remainder of the year is quite simple. High irrigation water requirements necessitate drawdown of the reservoir to content 2,200 acre-feet on September 30. Recovery of storage during October, November, and December is slow, and at the end of the year, there is only 3,500 acre-feet of stored water in the joint-use space.

VALUE OF PARAMETER-TYPE OPERATION .15 Looking back on the reservoir operation for this year, it is evident that downstream flows were limited to channel capacity at all times and yet the reservoir was filled by the end of the flood season. Without regulation, downstream flows would have exceeded safe channel capacity during 6 days in May and 12 days in June. The objective of optimum utilization of joint-use space . . . providing flood control space as required and also filling . . . was accomplished.

EXAMPLE 1
HYPOTHETICAL EXAMPLE OF HISTORICAL FLOOD ANALYSIS

(1,000 acre-feet)

Date	Volume of run-off at critical downstream point in excess of 2,000 cfs		Volume of run-off at critical downstream point		Remarks
	For Given Period	Inverse Summa-tion	For Given Period	Inverse Summa-tion	
(1)	(2)	(3)	(4)	(5)	(6)
April 26-30	-13.4	0	6.6	298.9	Begin flood control draw-down April 26
May 1-15	-12.2	13.4	47.8	292.3	
May 16-19	- 4.5	25.6	11.5	244.5	
May 20-31	14.5	30.1	62.5	233.0	Begin flood storage May 20
June 1-15	13.7	15.6	73.7	170.5	
June 16-18	1.9	1.9	13.9	96.8	End flood storage June 18
June 19-30	0	0	40.3	82.9	
July 1-31	--	--	42.6	42.6	End flood season July 31

Column (1). Semi-monthly time periods can usually be used except that these periods are broken down to isolate the significant dates listed in Column (6).

Column (2). Volume of runoff above 2,000 cfs. Begin tabulation June 18 and work backwards to April 26. Isolate significant dates. Carry inverse summation (Column (3)) along at same time. Negative volumes indicate that flow is below 2,000 cfs.

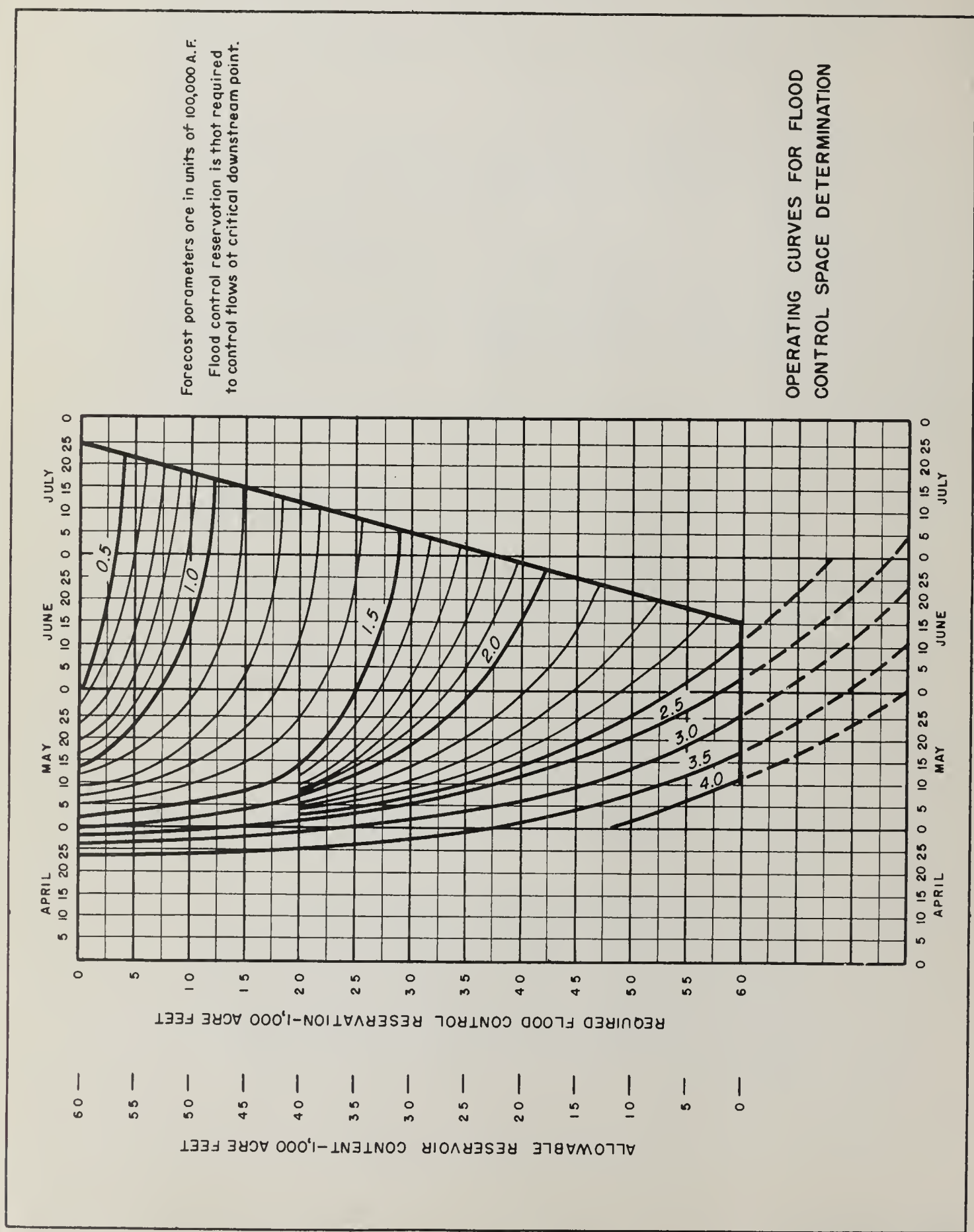
Column (3). Algebraic summation, carried from June 18 to April 26. This summation represents the reservoir storage space required for flood control at various times.

Column (4). Daily discharges at critical downstream point converted to acre-feet for the indicated period.

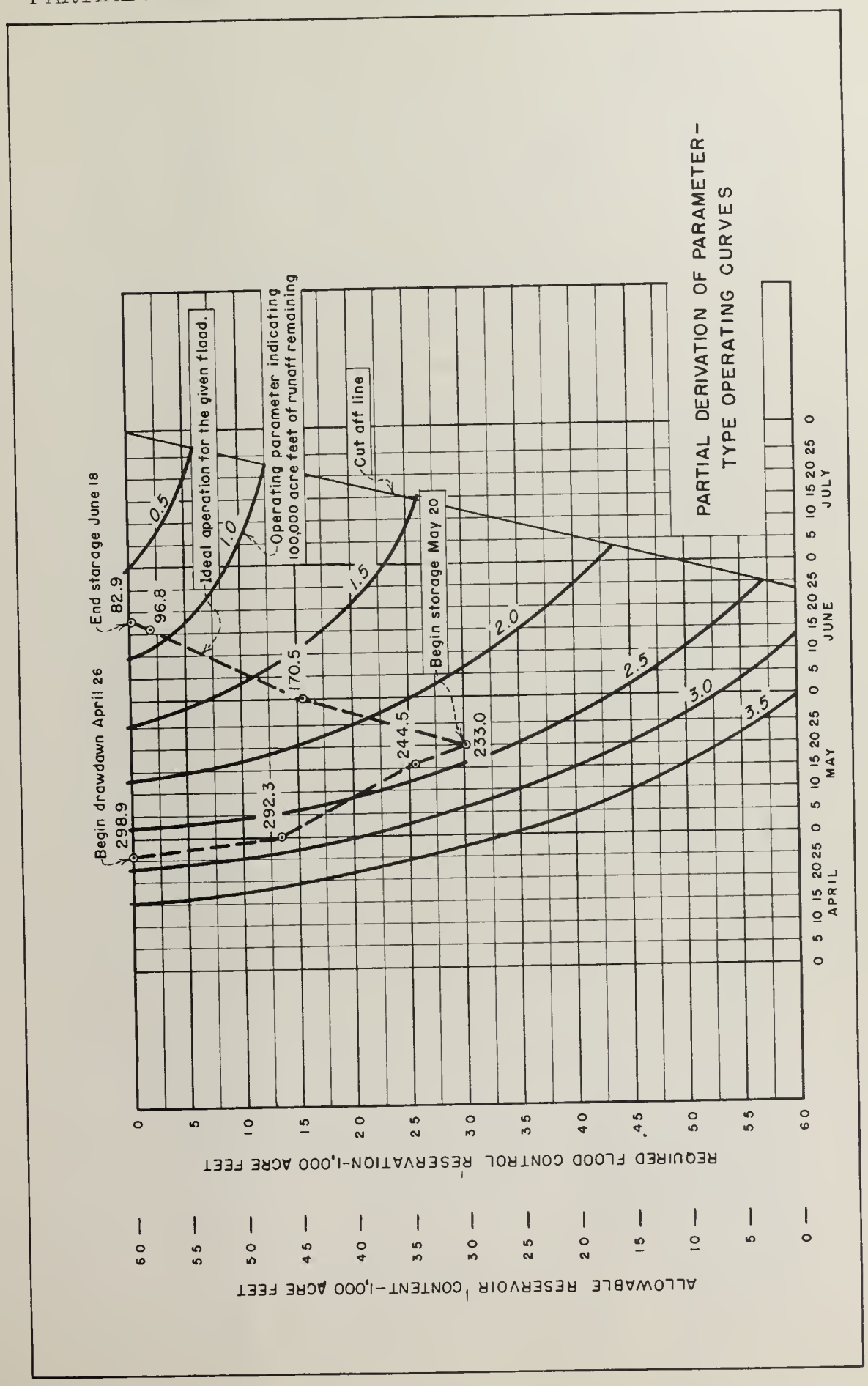
Column (5). Summation of Column (4), from July 31 to April 26. This summation indicates the volume of runoff which will occur from the given date to the end of the flood season on July 31.

Column (6). Significant dates. Date of initial drawdown is determined by converting daily discharges to acre-feet, and adding from April 30 until the day on which the cumulative total volume that could be released without exceeding a flow of 2,000 cfs equals 13,400 acre-feet (April 26). Date of first storage is the day on which flows rise significantly above 2,000 cfs. Slight rises above 2,000 cfs, followed by compensating falls below 2,000 cfs, are disregarded. Date of last storage is the day on which flows definitely fall below 2,000 cfs. Date of end of flood season is the day when discharges return to normal base flow.

EXAMPLE 2
OPERATING CURVES FOR FLOOD CONTROL SPACE DETERMINATION



EXAMPLE 3
PARTIAL DERIVATION OF PARAMETER-TYPE OPERATING CURVES



EXAMPLE 4
HYPOTHETICAL EXAMPLE OF PARAMETER-TYPE OPERATION STUDY

HYPOTHETICAL EXAMPLE OF PARAMETER-TYPE OPERATION STUDY

Unit: 1,000 Acre-Feet

Date and Month	Forecast of runoff at critical downstream point: 1st of month to July 31	Minus minimum runoff of record 1st of month to May 20	May 20 to July 31	Max. allowable res. content: 1st of month	May 20	End of month	Natural runoff at critical downstream point	Inflow to Reservoir	Outflow from reservoir: Irrigation release	Reservoir losses	Flood control by-pass	Flood control draw-down	Spill	Total	Change in Storage	Reservoir content end of month	Regulated runoff at critical downstream point
1942													(End of Dec.)			51.3	
Jan							2.3	0.5	0	0	0	0	0	0	+ 0.5	51.8	1.8
Feb							1.9	0.5	0	0	0	0	0	0	+ 0.5	52.3	1.4
Mar	250.0	30.3	219.7	60.0	21.5	40.5	3.9	1.4	0	0	1.4	11.8	0	13.2	-11.8	40.5	15.7
April	244.4	27.7	216.7	60.0	23.0	30.0	23.0	6.1	0	0	6.1	10.5	0	16.6	-10.5	30.0	33.5
May	See daily operation						80.5	21.6	0	0	10.5	12.0	0	22.5	- 0.9	31.1	81.4
June	See daily operation						101.7	35.5	0	0	5.8	0	0.8	6.6	+28.9	60.0	72.8
July							26.3	8.9	33.5	0	0	0	0	33.5	-24.6	35.4	17.4
Aug							7.8	2.2	31.4	0	0	0	0	31.4	-29.2	6.2	5.6
Sept							4.3	1.0	5.0	0	0	0	0	5.0	- 4.0	2.2	3.3
Oct							3.3	0.5	0	0	0	0	0	0	+ 0.5	2.7	2.8
Nov							3.1	0.7	0	0	0	0	0	0	+ 0.7	3.4	2.4
Dec							2.2	0.5	0	0.4	0	0	0	0.4	+ 0.1	3.5	1.7
Total							260.5	79.4	69.9	0.4	23.8	32.3	0.8	127.2	-47.8		237.8

HYPOTHETICAL EXAMPLE OF DAILY OPERATION DURING CRITICAL PERIOD

(Acre-Feet)

	Estimated day of	Forecast of runoff at critical downstream point					Max. allowable reservoir content		Natural runoff at	Inflow to Reser-	Outflow from reservoir						Change in storage	Reservoir content	Regulated runoff
11		124,500	46,000	78,500			54,500		4,400	1,560	0	0	0	0	0	0	+1,560	45,040	2,840
12									4,480	1,520	0	0	0	0	0	0	+1,520	46,560	2,950
13									4,180	1,440	0	0	0	0	0	0	+1,440	48,000	2,740
14									4,020	1,280	0	0	0	0	0	0	+1,280	49,280	2,740
15									3,180	1,140	0	0	0	0	0	0	+1,140	50,420	2,040
16									3,520	1,300	0	0	0	0	0	0	+1,300	51,720	2,220
17									3,680	1,460	0	0	0	0	0	0	+1,460	53,180	2,220
18									3,980	1,580	0	0	0	0	0	0	+1,580	54,760	2,400
19		124,500	76,900	47,600			57,000		3,840	1,520	0	0	0	0	0	0	+1,520	56,280	2,320
20									3,520	1,380	0	0	0	0	0	0	+1,380	57,660	2,140
21		124,500	83,600	40,900			58,000		3,240	1,280	0	0	940	0	0	940	+ 340	58,000	2,900
22									2,900	1,200	0	0	1,200	0	0	1,200	0	58,000	2,900
23									2,640	1,160	0	0	1,160	0	0	1,160	0	58,000	2,640
24									2,520	1,040	0	0	40	0	0	40	+1,000	59,000	1,520
25		124,500	93,800	30,700			59,000		2,120	880	0	0	880	0	0	880	0	59,000	2,120
26									1,860	800	0	0	800	0	0	800	0	59,000	1,860
27									1,760	760	0	0	760	0	0	760	0	59,000	1,760
28		124,500	99,000	25,500			60,000		1,560	640	0	0	0	0	0	0	+ 640	59,640	920
29									1,380	600	0	0	0	0	240	240	+ 360	60,000	1,020
30									1,340	600	0	0	0	0	600	600	0	60,000	1,340
Total									101,720	35,560	0	0	5,780	0	840	6,620	+28,940		72,770

CHAP. 5.3 RESERVOIR OPERATION STUDIES
APPENDIX I SAMPLE COMPUTATIONS--PARAMETER CURVE OPERATION

EXAMPLE 5
HYPOTHETICAL EXAMPLE OF DAILY OPERATION DURING CRITICAL PERIOD

HYPOTHETICAL EXAMPLE OF DAILY OPERATION DURING CRITICAL PERIOD

(Acre-Feet)

Date	Estimated day of initial storage	Forecast of runoff at critical downstream point: From 1st of month to July 31	Minus experienced runoff from 1st of month to given day	From given day to July 31	Minus minimum runoff of record from given day to day of initial storage	From day of initial storage to July 31	Max. allowable reservoir content: On given day	On day of initial storage	Natural runoff at critical downstream point	Inflow to Reservoir	Outflow from reservoir: Irrigation release	Reservoir losses	Flood control by-pass	Flood control drawdown	Spill	Total	Change in storage	Reservoir content end of day	Regulated runoff at critical downstream point
																	(End of April)	30,000	
May 1	May 20	242,200	0	242,200	19,200	223,000	49,000	20,000	700	140	0	0	140	3,300	0	3,440	-3,300	26,700	4,000
2									800	160	0	0	160	3,200	0	3,360	-3,200	23,500	4,000
3									760	160	0	0	160	3,240	0	3,400	-3,240	20,260	4,000
4	May 20	242,200	3,200	239,000	16,400	222,600		20,000	900	180	0	0	180	260	0	440	- 260	20,000	1,160
5									1,180	240	0	0	240	0	0	240	0	20,000	1,180
6	May 20	242,200	5,700	236,500	15,300	221,200		21,000	1,380	280	0	0	0	0	0	0	+ 280	20,280	1,100
7									1,680	360	0	0	0	0	0	0	+ 360	20,640	1,320
8									1,960	440	0	0	0	0	0	0	+ 440	21,080	1,520
9	May 20	242,200	11,700	230,500	13,200	217,300		23,000	2,340	520	0	0	0	0	0	0	+ 520	21,600	1,820
10									2,800	640	0	0	0	0	0	0	+ 640	22,240	2,160
11									3,040	700	0	0	0	0	0	0	+ 700	22,940	2,340
12	May 20	242,200	20,400	221,800	10,000	211,800		24,500	2,920	700	0	0	0	0	0	0	+ 700	23,640	2,220
13									2,160	520	0	0	0	0	0	0	+ 520	24,160	1,640
14									1,860	440	0	0	0	0	0	0	+ 440	24,600	1,420
15	May 20	242,200	26,400	215,800	6,200	209,600		25,500	1,880	480	0	0	0	0	0	0	+ 480	25,080	1,400
16									1,820	460	0	0	60	0	0	60	+ 420	25,500	1,400
17									1,880	500	0	0	500	0	0	500	0	25,500	1,880
18	May 20	242,200	32,100	210,100	2,100	208,000		26,000	2,000	520	0	0	20	0	0	20	+ 500	26,000	1,500
19	May 20	242,200	34,100	208,100	1,400	206,700		27,000	2,180	560	0	0	0	0	0	0	+ 560	26,560	1,620
20	May 20	242,200	36,800	205,400	0	205,400		27,000	2,560	700	0	0	260	0	0	260	+ 440	27,000	2,120
21	May 21	242,200	39,900	202,300	0	202,300		27,500	3,080	840	0	0	340	0	0	340	+ 500	27,500	2,580
22	May 22	242,200	43,500	198,700	0	198,700		28,500	3,560	1,000	0	0	0	0	0	0	+1,000	28,500	2,560
23	May 23	242,200	47,300	194,900	0	194,900		28,500	3,780	1,060	0	0	1,060	0	0	1,060	0	28,500	3,780
24	May 24	242,200	51,000	191,200	0	191,200		29,000	3,680	1,060	0	0	560	0	0	560	+ 500	29,000	3,180
25	May 25	242,200	55,100	187,100		187,100		29,500	4,180	1,220	0	0	720	0	0	720	+ 500	29,500	3,680
26									4,320	1,260	0	0	940	0	0	940	+ 320	29,820	4,000
27									4,740	1,420	0	0	680	0	0	680	+ 740	30,560	4,000
28		242,200	68,200	174,000			30,000		4,120	1,240	0	0	1,120	0	0	1,120	+ 120	30,680	4,000
29									4,320	1,340	0	0	1,020	0	0	1,020	+ 320	31,000	4,000
30									4,060	1,260	0	0	1,200	0	0	1,200	+ 60	31,060	4,000
31		242,200	80,500	161,700			32,500		3,820	1,180	0	0	1,180	0	0	1,180	0	31,060	3,820
Total									80,460	21,580	0	0	10,540	10,000	0	20,540	+1,060		79,400
June1		124,500	0	124,500			44,000		3,980	960	0	0	0	0	0	0	+ 960	32,020	3,020
2									4,100	1,060	0	0	0	0	0	0	+1,060	33,080	3,040
3									4,240	1,260	0	0	0	0	0	0	+1,260	34,340	2,980
4									4,160	1,160	0	0	0	0	0	0	+1,160	35,500	3,000
5									3,960	1,200	0	0	0	0	0	0	+1,200	36,700	2,760
6									4,160	1,340	0	0	0	0	0	0	+1,340	38,040	2,820
7									4,580	1,400	0	0	0	0	0	0	+1,400	39,440	3,180
8									4,160	1,320	0	0	0	0	0	0	+1,320	40,760	2,840
9									4,240	1,340	0	0	0	0	0	0	+1,340	42,100	2,900
10									4,020	1,380	0	0	0	0	0	0	+1,380	43,480	2,640
11		124,500	46,000	78,500			54,500		4,400	1,560	0	0	0	0	0	0	+1,560	45,040	2,840
12									4,480	1,520	0	0	0	0	0	0	+1,520	46,560	2,950
13									4,180	1,440	0	0	0	0	0	0	+1,440	48,000	2,740
14									4,020	1,280	0	0	0	0	0	0	+1,280	49,280	2,740
15									3,180	1,140	0	0	0	0	0	0	+1,140	50,420	2,040
16									3,520	1,300	0	0	0	0	0	0	+1,300	51,720	2,220
17									3,680	1,460	0	0	0	0	0	0	+1,460	53,180	2,220
18									3,980	1,580	0	0	0	0	0	0	+1,580	54,760	2,400
19		124,500	76,900	47,600			57,000		3,840	1,520	0	0	0	0	0	0	+1,520	56,280	2,320
20									3,520	1,380	0	0	0	0	0	0	+1,380	57,660	2,140
21		124,500	83,600	40,900			58,000		3,240	1,280	0	0	940	0	0	940	+ 340	58,000	2,900
22									2,900	1,200	0	0	1,200	0	0	1,200	0	58,000	2,900
23									2,640	1,160	0	0	1,160	0	0	1,160	0	58,000	2,640
24									2,520	1,040	0	0	40	0	0	40	+1,000	59,000	1,520
25		124,500	93,800	30,700			59,000		2,120	880	0	0	880	0	0	880	0	59,000	2,120
26									1,860	800	0	0	800	0	0	800	0	59,000	1,860
27									1,760	760	0	0	760	0	0	760	0	59,000	1,760
28		124,500	99,000	25,500			60,000		1,560	640	0	0	0	0	0	0	+ 640	59,640	920
29									1,380	600	0	0	0	0	240	240	+ 360	60,000	1,020
30									1,440	600	0	0	0	0	600	600	0	60,000	1,140
Total									101,730	33,360	0	0	5,780	0	840	6,620	+28,940		72,770

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CHAP. 5.4 COORDINATION OF OPERATIONS IN SYSTEMS

INTRODUCTION

.1 Reservoir operation studies frequently become complicated when several reservoirs are operated in combination for multiple purposes. Such operation studies are vital to proper planning of facilities to insure the most economical determination of the size of reservoirs and appurtenant works, and the most efficient planning for use of water. Such studies frequently involve exchanges of water and power. Studies of this type may involve reservoirs and works along one stream, a basin, or several interconnected basins.

ORGANIZATION OF STUDY

.2 Pertinent basic information should be assembled as described in Chapter 5.3 and other parts of the Manual. Organization of the study is dictated to a large extent by plans for the development and should be so arranged as to provide a sequence of logical steps in handling the water supply and to avoid repetition. Frequently these studies are made unnecessarily cumbersome, awkward to handle, and difficult to understand, because of careless planning. Every effort should be made to reduce the actual operation study to its simplest form by use of supplementary tables and curves. Because of the many factors being considered, many trial studies are frequently necessary to develop the most efficient plan of operation. If the studies are unnecessarily lengthy and time-consuming, time allotted for completion of the studies may not be adequate to allow sufficient trial studies.

OPERATING CRITERIA

.3 In order that a coordinated operation study may be completed with uniformity, it is usually desirable to establish operating criteria prior to initiation of the study. As changes are made in these criteria, care should be taken to make necessary adjustments throughout uncompleted studies. Establishment of criteria will be governed by known or suspected characteristics of the development plan, priorities of water use, water rights, compacts and treaties, and other pertinent items. As operation studies progress, changes in criteria should be made to develop the most efficient plan. Few criteria will be found common to all coordinated operation studies. However, there are several general considerations which should be made in initiating studies. As a general rule upstream reservoirs should be filled first to conserve water for later use. Such a procedure is generally helpful in avoiding spills from the basin or system due to lack of storage space to control waters originating downstream. It may also be helpful in effecting exchanges of water and avoiding evaporation losses which usually are less at higher elevations. Holding of storage water in the higher reservoirs will also frequently allow most effective use of power head. Another general rule which merits consideration is the release of water to meet a consumptive demand nearest the point of use. Such a procedure is effective in avoiding transit losses and wastes. Good control of released water is very helpful in efficient irrigation and project management. Flood control releases should be utilized insofar as possible without jeopardizing flood control functions. See Parts 2 and 6 for further information regarding flood control problems. Care should be taken to consider the multiple uses which can be made of various releases and the order of priority for such releases. As an example, releases for salinity control may be useful also for power, navigation, fish and wildlife, and other purposes.

FORECASTS

.4 The methods of forecasting runoff, considered in detail in Chapter 8.1 of this Volume, are of great value in establishing the operating criteria for a system of reservoirs. By methods of forecasting, the reservoirs can be evacuated in preparation for control of flood runoff, utilizing the releases to the best advantage with respect to power generation, and maintain or build up sufficient storage to meet requirements for irrigation. Joint-use space, the operation of which is discussed in detail in Appendix I, Chapter 5.3 of this Volume, is desirable in any reservoir where its use is possible, as it combines a portion of the flood control and conservation space, making more efficient use of the total capacity. The possibility of obtaining joint-use space should be investigated wherever forecasts can be accomplished.

OTHER MULTIPLE USES

.5 The most important multiple uses of Bureau of Reclamation reservoirs are commonly irrigation, power, and flood control. However, requirements for other uses such as municipal supplies, navigation, fish and wildlife propagation, salinity control, stream pollution abatement, sediment control, and other miscellaneous uses are frequently included. Part 4 of this Volume and Volume VII, Associated Multiple Functions, should be consulted when working with any of the uses mentioned above.

CHAP. 5.5 GRAPHICAL REPRESENTATION OF OPERATIONS

GENERAL

.1 After a complete operation study has been performed, it is highly desirable to show the results graphically. Operation studies can be readily understood and visualized through graphical diagram. The discussion and illustrations which follow have been prepared for general guidance in presenting graphs of operation studies.

PLOTTING DATA

.2 The data required to plot the results of an operation study are ordinarily obtained directly from the study work sheets. In operation studies it is usually necessary to minimize the number of tabulations to permit rapid, accurate work. This is particularly true in preliminary studies. The trial and error nature of such studies makes it virtually impossible to predict the adequacy of the study in yielding results requiring graphical representation; therefore, it may be necessary to make additional computations for use in plotting graphs. These supplementary calculations are usually simple summations of data contained in the study.

PRESENTATION OF GRAPHS

.3 It is of prime importance to present the results of an operation study, insofar as practical, by parallel graphs on the same sheet by using identical time intervals as abscissa. The selection and arrangement of graphs is dependent upon the features illustrated and most practical selection of scales. In any event, consideration must be given to grouping of graphs which will permit ready, visual comparisons. The adequacy of graphs to represent properly an operation study is dependent largely upon the wise preparation of the drawings. Ordinarily, curves and diagrams representing the operation features are plotted on graph paper preliminary to their assembly on the final drawings. It is well-advised to consider at that time the scales and arrangements of subject matter which will be proper for inclusion on the final drawings. Adequate space should be allowed to accommodate explanatory notes which are needed to assist in reading and understanding the graphs. Insofar as possible, preparation of final drawings must be governed by drafting standards which are discussed in Chapter 1 of Design Supplement No. 1 to Volume X. In general, it is desirable to present graphs which illustrate, for the period of operation, reservoir content, inflow to reservoir, outflow from reservoir, demands on reservoir storage, shortages, and output of hydroelectric energy when generated at multiple-purpose projects. Additional graphs will be desirable to illustrate specific conditions in unusual cases. Typical operation graphs are included with this chapter as Illustration 1 for a simple operation and Illustration 2 for a multiple-purpose project.

RESERVOIR CONTENT

.4 A curve connecting ordinates equal to reservoir content at the end of the month or other period should be used to show reservoir content. Such a graph is suitable to illustrate an individual reservoir as depicted by Graph C on Illustrations 1 and 2, or can be used for a system of reservoirs. Reservations for flood control, conservation, dead storage, or other storage allocations should be delineated appropriately. It is seldom possible to show the allocation for sedimentation on this or other operation graphs; however, consideration should be given to the use of notes on the graph in explaining sedimentation allocations. (See Paragraphs 9.1.3, 9.4.1E, and 9.4.11 of Volume VII.)

INFLOW TO RESERVOIR

.5 Bar diagrams of inflow to a reservoir are necessary to illustrate the reservoir's regulating effect on the stream. This inflow to the reservoir is commonly depicted as shown by Graph A on Illustrations 1 and 2. It may be desirable to plot outflow from the reservoir on the same graph to effectively show inflow-outflow comparisons. In any case, abscissa of time should be the same as in the other graphs plotted on an operation chart.

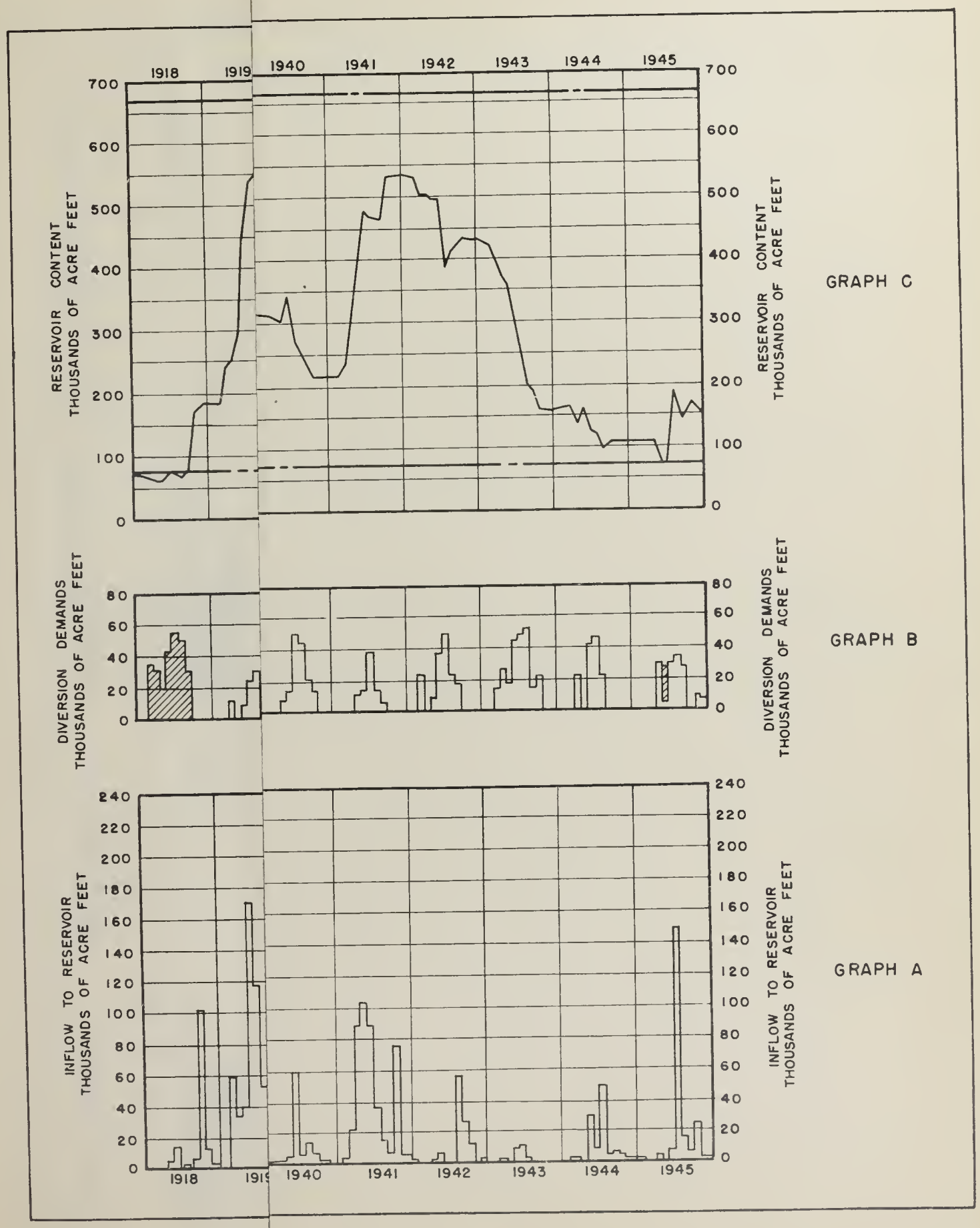
OUTFLOWS FROM RESERVOIR & SHORTAGES

.6 Outflows from a reservoir are comprised of controlled releases from storage for the various water requirements discussed in Part 4, and spills which cannot be retained in the reservoir under the particular operating conditions. It should be noted that uncontrolled losses from storage by evaporation, seepage, or other causes are not commonly represented by specific graphs but are elements which enter into the storage content curve. It might be desirable, in an unusual case, to show by suitable graphs the loss of water from storage for these items. Because of the wide range of possible conditions, no illustrations are included

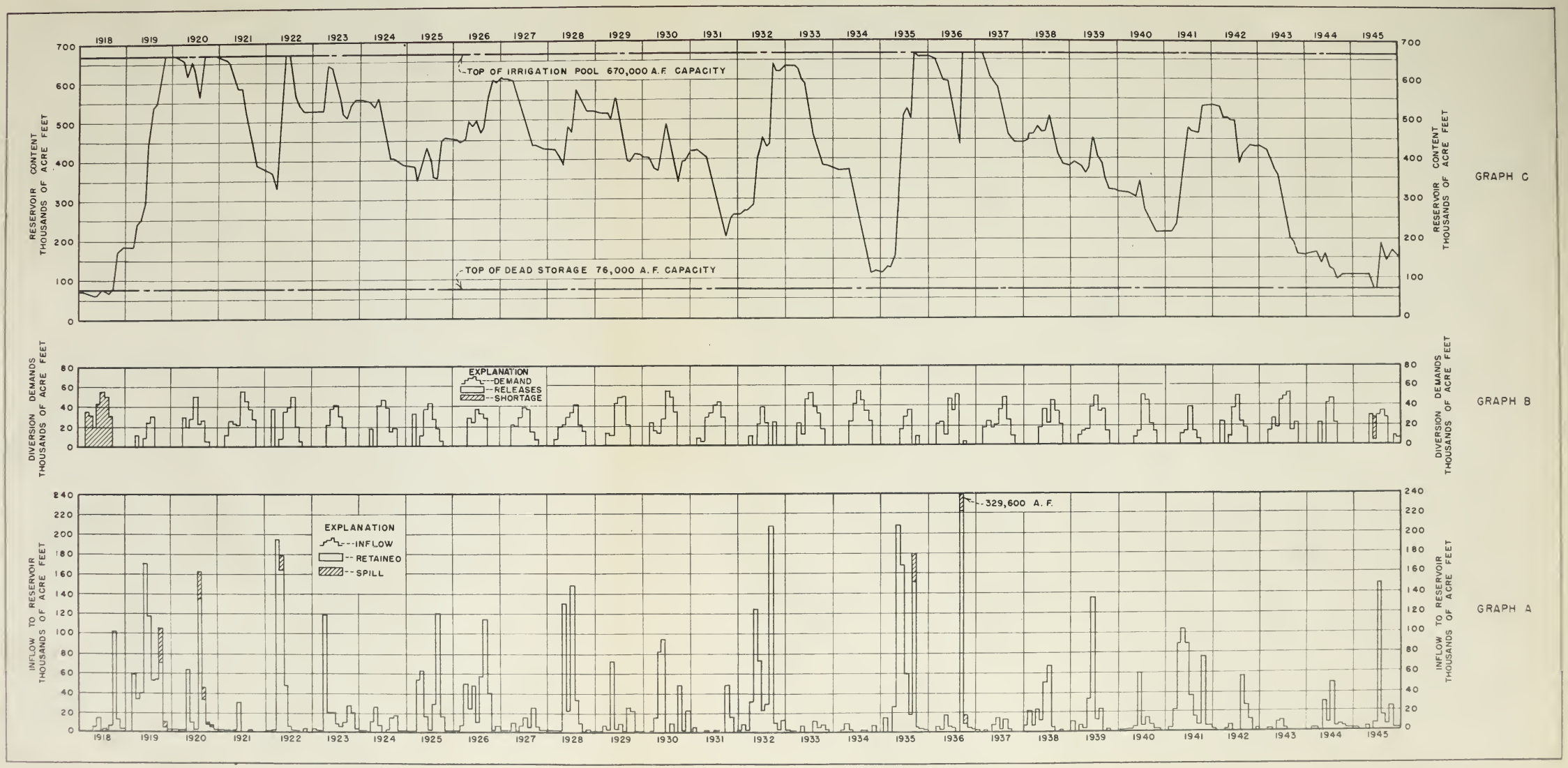
with this discussion. Outflows can be shown with the inflow graph as discussed in the preceding paragraph, but they are more often shown by separate bar diagrams depicting releases for the various demands on the reservoir storage and the occurrence of shortages and spills. It may be desirable to show the occurrence of spills as a part of the inflow graph as shown by Graph A of Illustration 1. Ways which can be used to show outflows and shortages are demonstrated by Graph B on Illustration 1.

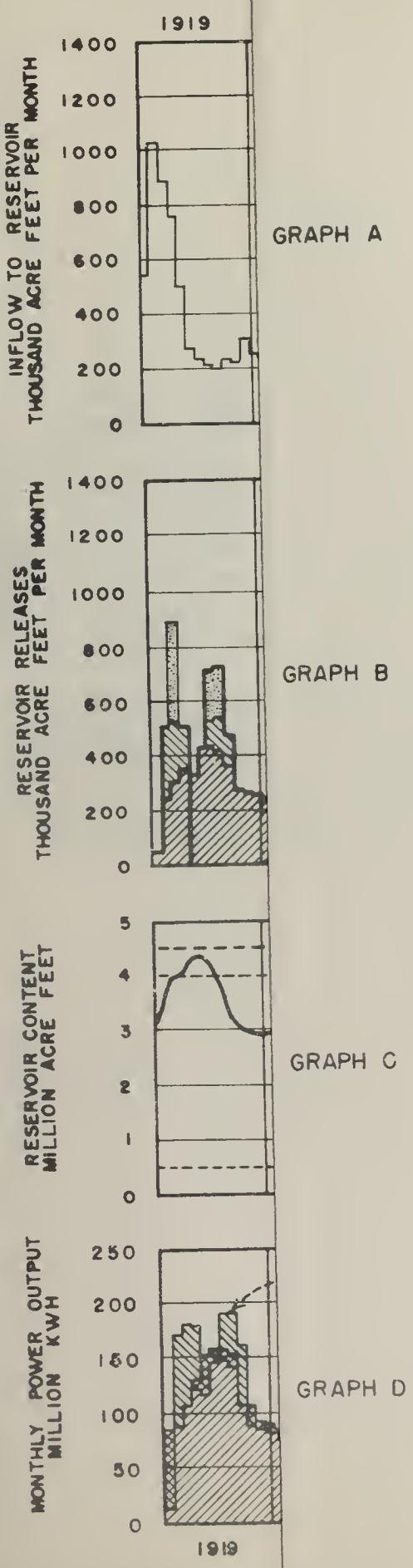
POWER PRODUCTION

.7 When power production is one of the purposes of a project, a graph should be prepared showing the amount of hydroelectric energy which can be produced by operation of the project. This graph should illustrate the production of firm, secondary, and dump energy if applicable. It is necessary to show the amount of electric energy produced by fuel-burning plants when interconnected as standby capacity with the hydroelectric plants. Graph D on Illustration 2 exhibits a typical graph of electric power produced by a hydroplant interconnected with a fuel-burning plant. This type of graph can be made to represent power produced by coordinated operation of several plants. It will be necessary in some cases to illustrate on the graph the production of firm power for the purpose of irrigation pumping as distinguished from the production of firm commercial energy. This can be accomplished by judicious use of hatching or notes. Duration curves are particularly useful in the graphical representation of operations in illustrating energy output in percent of time of the study period. Frequently the curves are shown for the critical and long-time periods as displayed by Illustration 3 and may be plotted in the same manner for several plants operated in combination.


1918
1919
1940
1941
1942
1943
1944
1945
RESERVOIR CONTENT THOUSANDS OF ACRE FEET
700
600
500
400
300
200
100
0
GRAPH C
DIVERSION DEMANDS THOUSANDS OF ACRE FEET
80
60
40
20
0
GRAPH B
INFLOW TO RESERVOIR THOUSANDS OF ACRE FEET
240
220
200
180
160
140
120
100
80
60
40
20
0
GRAPH A

TYPICAL GRAPH FOR A SINGLE OPERATION





EXPLANATION

- Release for irrigation, navigation and salinity control.
- Additional release for flood control and power purposes.
- Use for production of firm power.
- Use for production of secondary power.
- Release in excess of power plant capability.

NOTES

Reservoir operated primarily to supply water for irrigation, navigation, and salinity control purposes with the initial project development.

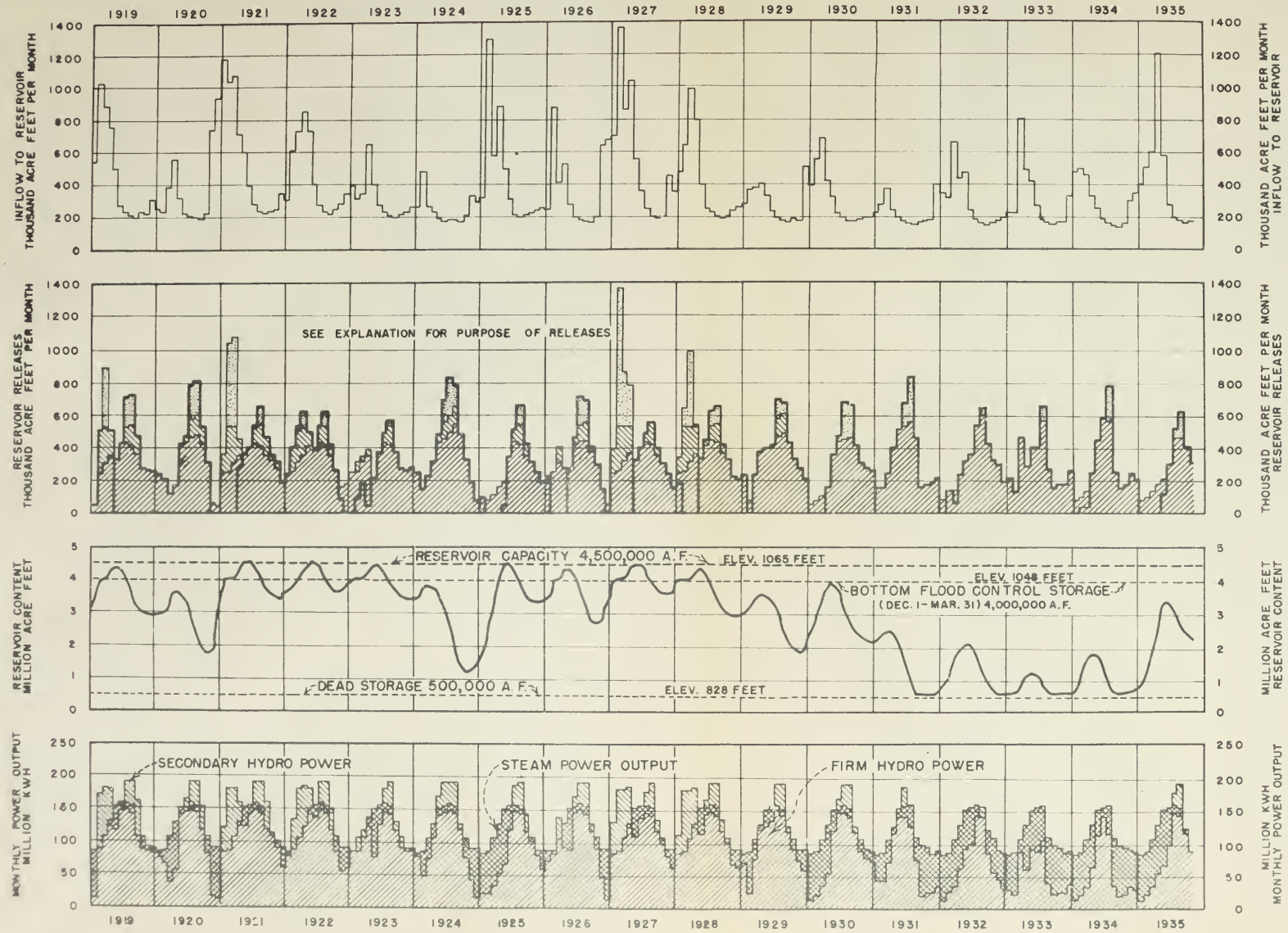
Output capacity of power plant_____ 280,000 Kw

Interconnection assumed with steam plant having an output capacity of_____109,000 Kw

Annual firm power delivered at _____:
Pumping plant requirements_____ 370,000,000 KWH
Firm commercial power_____1,063,000,000 KWH

TOTAL____1,433,000,000 KWH

TYPICAL GRAPH FOR A MULTIPLE-PURPOSE PROJECT



EXPLANATION

- Release for irrigation, navigation and salinity control.
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Annual firm power delivered at _____

Pumping plant requirements_____ 370,000,000 KWH

Firm commercial power_____ 1,063,000,000 KWH

TOTAL____ 1,433,000,000 KWH

Department of the Army
Board of Engineers for Rivers and Harbors
Building T-7, Gravelly Point
Washington 25, D. C.

Herewith is a copy of a revised report on the Ports of Gulfport and Pascagoula, Miss., compiled by the Board of Engineers for Rivers and Harbors, Corps of Engineers, Department of the Army, and the United States Maritime Commission, and published as Port Series No. 19. Reports in this series cover the principal ports of the United States and are prepared to meet the needs of the Government and to supply data for use of importers, exporters, manufacturers, railroads, steamship lines, and others interested in the development of harbors and the establishment of port and terminal facilities.

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FOR THE BOARD:

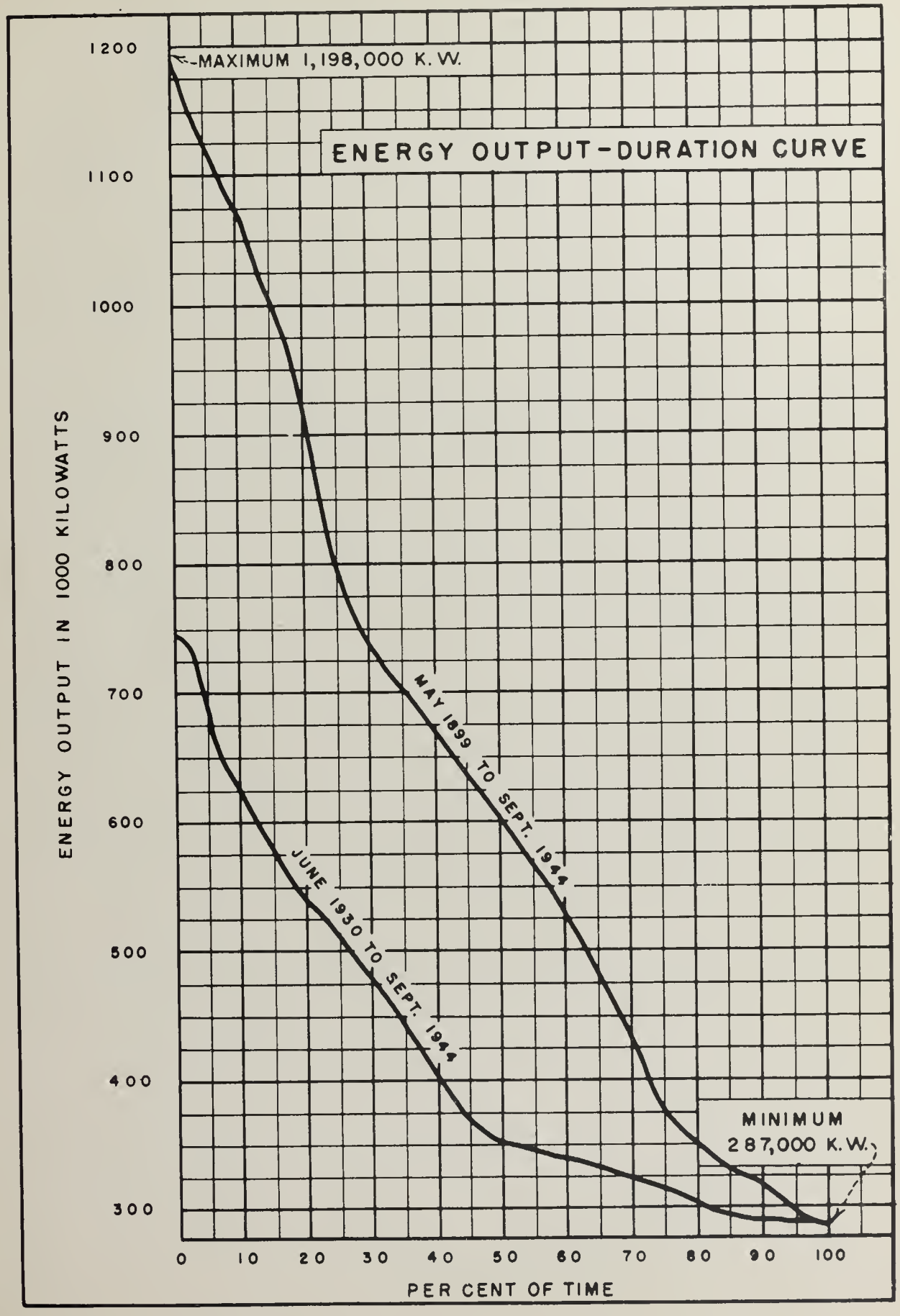
Sincerely yours,

Henry F. Hannis

HENRY F. HANNIS
Colonel, Corps of Engineers
Resident Member

Incl -
P.S. No. 19

ENERGY OUTPUT--DURATION CURVE



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.1 Flood hydrology, as applied to the activities of the Bureau of Reclamation, consists of those phases of hydrology, meteorology, and statistical method that pertain to the estimating of flood volumes and discharge rates under hypothetical conditions. The most important of such studies are the estimates of maximum probable floods to be used in determining the required spillway capacities for dams. Other important studies include the frequency of floods of various magnitudes, particularly those used to determine the diversion requirements during construction of dams. The procedures offered in the following chapters are considered the best available at the time of writing. Many of them will sooner or later be rendered obsolete by newer developments in the hydrologic field. It is important, therefore, that the hydrologists of the Bureau should at all times be familiar with the current professional literature dealing with these topics. The Hydrology Division, Branch of Project Planning, is continuously engaged in experimenting with new methods; reviewing procedures originating from other sources; and assisting Regional, area, and project offices of the Bureau in developing ideas originating there. SCOPE

.2 Inflow design flood studies are made for use in preparing preliminary designs and estimates for dams and other hydraulic structures and after additional review, are used in the preparation of final designs and specifications. They are also used in laying out programs for test drilling and for other preliminary investigations and basin reports. For these latter purposes, including the drilling program, brief studies known as "tentative" inflow design flood studies are usually acceptable. DESIGN FLOOD STUDY

A. The general principles and policy governing the determination of the required spillway capacity are discussed in Chapter 7.5. It will be noted that in certain cases the use of an inflow design flood less severe than the maximum probable is justified. Ordinarily, however, the required spillway capacity of a storage dam is determined by routing the maximum probable inflow flood through the assumed reservoir storage (see Paragraph 6.1.5).

B. Every inflow design flood study, when completed, is presented in the form of a memorandum report. The report must be sufficiently detailed so that the procedure is clearly indicated and can be followed by readers who may wish to review the conclusions reached. Copies submitted for formal review must be accompanied by the basic data and all of the processing and other computations, that are essential to a detailed review of the study. Such tables, curves, and work sheets may be in penciled form and will be returned, upon request, to the office submitting the report. A typical outline for the memorandum report is shown in Paragraph 6.1.8.

C. The report of the inflow design flood study is reviewed in the Regional Office for adequacy, soundness, and accuracy. In general, the following facts should be verified (a less rigorous review may be made of "tentative" studies):

(1) All basic data that are pertinent and available have been collected and utilized to the best advantage.

(2) Computations have been checked, except where there is an automatic check or a check is obviously unnecessary.

(3) Assumptions that have been made are in accord with sound practice and established Bureau policy.

(4) Procedures followed are up to date and logical.

(5) Results are substantiated by the use of more than one approach when practicable.

DESIGN FLOOD STUDY (Cont.)

(6) Results have been compared critically with those already obtained in the basin or in similar basins nearby, and with floods of record in the same geographic and climatological zone.

(7) The method of performing the study, bases of assumptions, and reasons for recommendations made are clearly expressed in the report.

The Regional Director, if satisfied with the report, submits it in duplicate to the Chief, Hydrology Division, Branch of Project Planning, with the recommendation that it be approved. One copy of the supporting data (see Subparagraph 6.1.2B) should accompany the report. The review by the Hydrology Division is similar to that outlined above, except that the computations are assumed to have been checked. The Chief, Hydrology Division, if satisfied with the report, will approve the inflow design flood for use in preliminary designs and estimates, or for final designs and specifications, as the case may be. If a flood has already been approved for preliminary design, it must still be specifically approved for final design before being used for that purpose. If sufficient time has elapsed so that new hydrologic or meteorological data may be available, or better procedures have been developed, the study should be critically examined and, if necessary, reviewed again, by both the Regional Office and the Hydrology Division before being approved for final design purposes.

INITIATION OF STUDIES

.3 The fundamentals of a design flood problem are the type of result required, the information that can be used to obtain it, and the effective utilization of that information. The study is initiated by examining the requirements and the data available, assuming one or more situations that might produce the design flood, and tentatively selecting one or more general procedures for determining the flood. The usual initial steps are as follows:

A. Establish the objective. The purpose, type, size, and importance of the structure should be considered. The degree of hazard created by it may affect the magnitude of the design flood, as discussed in Chapter 7.5. The proposed reservoir capacity will often determine whether the critical flood will be a protracted one of large runoff volume, resulting from snowmelt, or a brief one with greater peak flow, resulting from rain.

B. Study the characteristics of the basin. The size, latitude, elevation, physiography, geology, drainage pattern, soils, vegetal cover, climatology, and meteorology of the watershed all affect the type of floods to be expected. The regimen of storm, snowmelt, and ground-water runoff and the discharge characteristics of the basin are best observed by plotting available records of daily discharge on semilog calendar paper. In small basins the probable areal extent of the reservoir should be determined, since the latter may alter the natural discharge characteristics of the stream by flooding out portions of the main and tributary channels.

C. Prepare an inventory of available basic data that may be applicable to the study, including stream gaging records, climatological records, topographic maps, geologic and soil maps, air photos, and previous hydrologic studies made in the same general area.

D. Set up one or more tentative plans for the study. Unless the problem is a simple one, it is highly desirable to hold preliminary consultations with the reviewing offices. With any method chosen for use in the study, certain basic assumptions of conditions affecting the design flood will have to be made. These may sometimes include the residual or "leading" flow, antecedent soil moisture, depth and areal extent of antecedent snow cover, changes in nature of ground cover and tilth, location of storm center, date of the spring thaw, magnitude of supplemental snow floods to occur in conjunction with maximum probable spring rain floods or of supplemental rain floods in conjunction with maximum probable snow

floods, minimum interval between successive rainstorms, operation schedules of other reservoirs, reliability of precipitation forecasts, and numerous other factors. They are dictated largely by the considerations of Subparagraphs A and B, above, in the light of current practice and Bureau policy. Since the element of judgment plays an important part in establishing the basic assumptions and selecting the procedures to be used, it is desirable that complete accord between the authors and reviewers be reached through mutual discussion of the problems involved. The discussion should take place after a survey of available basic data and other information has been made and before a definite plan for the study has been selected. In order to reduce the chance of performing unnecessary work, the office initiating the study should outline one or more plans and submit them to the Regional Office. After consideration and discussion by both offices a tentative plan should be submitted by the Regional Office to the Hydrology Division. Further discussion between the latter two offices should be conducted as found necessary, and a definite agreement reached in regard to the basic assumptions and general procedures to be used in the study.

INITIATION OF STUDIES (Cont.)

METHOD

.4 The procedures suggested for use in developing inflow design floods are discussed in Chapters 6.2 to 6.10, inclusive. The methods selected will depend upon the degree of accuracy required, the time allowed, and the basic data available. Except where snowmelt is the predominant factor, the principal basis of the inflow design flood is the design rainstorm (see Chapter 6.5). Design storm studies may be performed by competent hydrometeorologists within the Region or they will be performed by the Hydrology Division, Branch of Project Planning, upon written request by the Regional Director. The design storm is discussed in Chapter 6.5 and its application is described in Chapter 6.8. Snowmelt runoff procedures are presented in Chapter 6.9. The peak and volume of the inflow design flood hydrograph as developed should be compared with the corresponding values obtained from envelope curves of observed peaks and volumes, keeping in mind that envelope curves indicate the magnitude of floods that have occurred during a relatively short period of time and cannot be presumed to fix the limit of future floods (see Chapter 6.3). In nearly all cases the maximum probable flood as defined below should be used as the inflow design flood.

A. The maximum probable flood is the flood assumed to result from the most critical of the following situations:

(1) The maximum possible rainstorm in conjunction with severe, but not uncommon, antecedent conditions.

(2) The maximum possible rainstorm for the season of heavy snowmelt, in conjunction with a major snowmelt flood somewhat smaller than the maximum probable.

(3) The maximum probable snowmelt flood in conjunction with a major rainstorm less severe than the maximum possible rainstorm for that season.

B. Tentative inflow design flood studies are not used for preliminary or final design and do not require the same degree of accuracy as the more detailed studies. Because of the limited time allowed, they are often based entirely upon envelope curves of observed floods and upon other inflow design floods previously computed for dams in the same general area. Note, however, that the tentative flood is actually an approximation of the flood that would be used for design and there should be no reason to assume that it is a lesser flood. Usually, therefore, a value picked from an envelope curve of observed peaks or volumes will need to be increased, according to the number and length of records represented by the curve, and the degree of safety required. Tentative studies are usually submitted to the Hydrology Division for review previous to their use in the preparation of preliminary estimates for basin-type planning reports.

ESTIMATE OF RESERVOIR CONTENT

.5 To route an inflow design flood through a reservoir to determine the required spillway capacity, it is necessary to assume the elevation of the reservoir pool at the start of the design flood.

A. The estimate should be based on a consideration of the spacing of maximum experienced storms where a rain flood is the criterion for spillway design. It would be unreasonable, for example, to assume that two maximum possible storms could follow immediately one upon another. However, in some areas of the West, the meteorological situation could be such that a major storm would occur just previous to the maximum possible storm, and in such areas it would be reasonable to assume that a storm producing a flood of perhaps a 50-year or 100-year frequency could occur immediately preceding the inflow design flood. Such an assumption will determine the elevation of the reservoir pool at the time of the start of the inflow design flood.

B. In areas where the inflow design flood is composed primarily of runoff from snowmelt, the reservoir elevation at the beginning of the design flood hydrograph should be assumed after considering the extent of snow surveys and the probable accuracy in predicting the snowmelt runoff in advance of the flood season. A routing recommendation quite often used in view of the present snow data and forecasting efficiency is that the inflow design flood be routed through the reservoir with the water surface of the reservoir at the top of the conservation pool at the beginning of the inflow design flood. However, other routing conditions may be recommended if these conditions are justified on the basis of the probable degree of accuracy attainable in forecasting the snowmelt floods.

DIVERSION REQUIREMENTS DURING CONSTRUCTION

.6 It is necessary to determine floods of 5-, 10-, and 25-year frequency to be used as a basis for estimating the diversion requirements during construction of a dam. (See Chapters 6.4 and 7.4.) The peak discharge and volume of the 5-, 10-, and 25-year floods are obtained from frequency analyses. The shape of the hydrographs is based upon the shape of the inflow design flood hydrograph, or upon the shape of a unit hydrograph considered applicable for the basin. The hydrographs for diversion requirements are ordinarily included with all inflow design flood studies, including tentative studies.

SPILLWAY CAPACITY OF DIVERSION DAMS

.7 The required spillway capacity for a diversion dam is not necessarily the maximum discharge that might possibly occur because failure of a diversion dam would rarely increase appreciably the flood downstream from the dam and therefore does not involve the safety of human life. The choice of a design spillway capacity is a matter of economics in which the cost of replacing the dam is the principal consideration. To arrive at an economic solution, it is necessary to resort to frequency analysis of occurrence of floods. Such an analysis may be made by one of the methods described in Chapter 6.4. Although the analysis may require extrapolation of the frequency data beyond the period of record, the extrapolation is not extreme, and therefore the analysis in such a case is considered sufficiently reliable.

FLOOD STUDY MEMORANDA

.8 After the inflow design flood hydrograph has been derived, a memorandum is written giving an appropriate discussion of data used, methods applied, and the results obtained. The outline below is given as a suggested sequence of the contents in the memorandum. It is realized that this outline cannot be followed rigidly in every flood study because of the different methods that are applicable in different basins. However, the outline will serve as a general guide in preparing the memorandum.

A. Introduction

1. Authorization of study

2. Reference to any previous studies

3. Summary of results of current study.

B. Description of basin

FLOOD STUDY MEMORANDA (Cont.)

1. Size and location of drainage area
2. Type of terrain, to include description of drainage pattern, prevailing slopes, and channel characteristics
3. Geology and ground-water characteristics
4. Soils and infiltration characteristics
5. Vegetation.

C. Streamflow records

1. Location of gages
2. Period of record
3. Maximum recorded floods
4. Historical floods.

D. Analyses of experienced storms

1. Description of storm analyzed
2. Results of analyses
   a. Initial loss
   b. Retention loss
   c. Unit hydrographs.

E. Maximum probable rain flood

1. Unit hydrograph
2. Retention loss
3. Design storm
4. Application of unit hydrograph to excess
5. Maximum probable rain flood hydrograph.

F. Snowmelt analyses

1. Temperature runoff relation
2. Derivation of maximum possible temperature
3. Estimate of maximum possible snow accumulation
4. Determination of maximum probable snow flood.

G. Envelope curves

1. Peaks
2. Volumes.

H. Probability curves

1. Peak
2. Volume.

FLOOD STUDY MEMORANDA (Cont.)

I. Comparison of results of various methods

1. Recommended inflow design flood.

J. Routing recommendation for inflow design flood

1. Initial level of water surface.

K. Diversion during construction

1. 5-, 10-, 25-year flood hydrographs

2. Period of flood expectancy

3. Period of low flow

4. Required minimum releases.

L. Supporting data

1. Copies of all basic and processed data and computations needed for review.

.1 In making flood studies it is necessary to ★obtain★ various types of data, of which the most common types are (1) rainfall, (2) snowfall and snow accumulation, (3) temperature, (4) runoff, and (5) sedimentation. TYPES

.2 The sources of basic data for the above factors are given in the subsequent paragraphs. A summary of the sources is given in Appendix I to this chapter, with maps showing the administrative regions or divisions covered by the major Governmental agencies which collect flood and related data. SOURCES

.3 Records of rainfall are gathered principally by the Weather Bureau of the Department of Commerce and published monthly and annually in Climatological Data, separately for each state. At present, Climatological Data contains hourly and daily precipitation amounts as well as other meteorological data. Previous to 1949, this publication did not include hourly precipitation data; precipitation data were then published in: RAINFALL

Climatological Data (daily precipitation) 1914 - 1948
Hydrologic Bulletin (daily and hourly precipitation) 1940 - 1948
Monthly Weather Review (daily precipitation) July 1909 - 1913.

Before July 1909, the equivalents of Climatological Data were published under the titles Climate and Crops and Climatological Report; these publications are, nevertheless, presently referred to as "Climatological Data." In several states very early precipitation records were published by the states themselves.

★ Since about September of 1951, much of the hourly data have not been published because of a lack of funds. Efforts are being made to resume the publication of these data in "Climatological Data." It is expected that the missing period will, in time, be published as a supplement to "Climatological Data." ★

A. The following types of Weather Bureau stations are engaged in the collection of precipitation data and related meteorological data:

(1) First-order stations (staffed by commissioned Weather Bureau personnel), taking detailed observations at intervals determined by the station's mission.

(2) Second-order stations (staffed by part-time employees), taking detailed observations at 6-hour or 3-hour intervals.

(3) Airway stations, taking on-call observations in connection with airway operations. ★(Some of these stations are operated by the CAA but records are kept by the Weather Bureau).★

(4) River and rainfall stations, taking river-stage and rainfall observations, usually for use by river forecasting centers.

(5) Crop stations, taking observations for use by the Weather Bureau in connection with its services to growers of various crops.

(6) Fruit-frost stations, taking observations for local use in forecasting frost in fruit-growing areas.

(7) Climatological and hydroclimatic stations (including unpaid cooperative observers), taking observations of temperature and precipitation for general climatological, hydrologic, and other uses.

★(8) Evaporation stations, taking observations of evaporation from pans. Lists of first-order stations, Regional Offices, state section centers, area engineer offices, records processing centers, and river district offices west of the Mississippi River are given in Appendix I to this chapter. Requests for data or information concerning first-order stations ((1) above) should be directed to the station involved or the

RAINFALL (Cont.)

appropriate section center. Requests for data or information concerning all substations ((2), (3), (5), (6), (7), and (8) above) should be directed to the appropriate state section center. The area hydrologic engineers as field representatives of the Washington office provide liaison with the other Federal agencies concerning expansions of the network and operation of stations. The records processing centers transcribe all recorder charts and publish the state "Climatological Data" bulletins mentioned above. Matters concerning reporting networks ((4) above) should be referred to the appropriate River District office.★

B. Descriptions and explanations of the use and expected accuracies of different forms used by the Weather Bureau in compiling rainfall data are given in its Cooperative Studies Section's Technical Paper No. 1, "Manual for Depth-Area-Duration Analysis of Storm Precipitation." Because this technical paper is complete in its treatment of basic rainfall data, no further explanation is given here of Weather Bureau rainfall data.

SUPPLEMENTAL STORM SURVEYS

.4 The Bureau of Reclamation requires data on historical and recent storms in connection with the preparation of inflow design floods and the setting up of operating procedures for flood routing through reservoirs. With the greater number of recording rain gages operating at present, as compared with the past, we obtain better data on current storms. However, the network of precipitation stations is still far from sufficient to give all data desired for detailed analyses of observed precipitation. It is therefore necessary, following outstanding storms, to supplement the data obtained at rain gages with unofficial observations. For greater reliability, the data should be collected as quickly as possible after the occurrence of the storm.

A. Within the Bureau of Reclamation the responsibility for recognizing particular storms as being outstanding and the collection of the unofficial rainfall data lies with the operating office in whose area the storm occurs. The occurrence of unusual precipitation may be indicated by newspaper reports of precipitation and stream stages and from observations available at local Weather Bureau offices. The plotting of available reports on a map of the area will be found helpful at this phase as well as later in the survey. If the available data show the possibility of rainfall rates, in any part of the area, for any duration, approaching the maximum observed for such area and duration, a field survey of the storm should be made. In general, reported rainfall equivalent to that of an actual or potential major flood-producing storm should be investigated.

B. When it is decided that a storm merits investigation, plans for the field survey should be coordinated with other interested agencies. Local offices of the Bureau of Reclamation in or near the storm area, the appropriate district or Regional Office of the Bureau of Reclamation, the appropriate Regional Office of the United States Weather Bureau, Geological Survey, state engineers, local agencies, and district office of the Corps of Engineers should be consulted to determine their interest in the field survey and whether they desire to participate in it. Plans should be adjusted to eliminate duplication of effort and to assure full coverage of the storm. In general, it is best to accomplish the necessary coordination in person or by telephone. Correspondence by mail involves too much delay for storm survey work.

C. It is difficult and not particularly desirable to give the interviewers hard and fast instructions on the routes they are to travel in obtaining the rainfall data. It is considered best procedure in general for the teams first to locate the center or centers of precipitation intensity and then to obtain data along lines crossing those centers. To a large extent the itineraries of the interviewers will be governed by the distribution of population in the storm area and the location and condition of the roads and bridges. County highway maps will be found useful in assigning areas to the separate crews. The instructions should be specific enough to preclude the omission of significant areas and the overlapping of work of different teams. Emphasis

SUPPLEMENTAL STORM SURVEYS (Cont.)

must be placed on obtaining every bit of pertinent information available, particularly near the centers of the storms. In planning the survey, it is helpful to inform the local residents of the existence and purpose of the survey and of the locations at which the teams may be reached. The use of newspaper stories and radio announcements is desirable in this connection.

(1) Form HD39 (Experimental) is intended for use in field surveys of storm precipitation. The upper part of the form is devoted to the identification of the observation and should be carefully filled out before leaving the site of the observation. Illustration 1 is a sample of the form properly filled out.

(2) The interviewer's approach should be businesslike, but pleasant and tactful. He should briefly explain the purpose of the survey and may, for the purpose of interest, mention some of the information already obtained. In interviewing the local residents, the times of beginnings and endings of precipitation should be obtained. If the precipitation was discontinuous or if its character varied, the beginnings and endings of the separate occurrences, heavy precipitation, and snow or hail should be obtained and entered on the form. The observation of thunder or lightning as well as strong winds or wind shifts should be noted. These data may be of value regardless of whether the person interviewed has actually measured the precipitation. Weather Bureau cooperative observers frequently do not enter much data on their forms beyond the amount of precipitation and it will nearly always be found profitable to interview them for the information described above.

(3) In obtaining measurements of precipitation, the most desirable receptacles are level, straight-sided, flat-bottomed containers standing in the clear. For these receptacles a direct measurement of the depth of water is satisfactory. If the container has been emptied without measurement, it is desirable to have the observer refill it and then measure the depth in the presence of the interviewer. This is also an effective check on the observation, if the measurement has been made previous to the interview. The depth is measured by inserting a thin ruler or steel tape vertically into the container. If the container was not empty at the beginning of the storm, the beginning depth should be subtracted from the total depth at the end of the storm. If several observations were made during the storm, the rainfall between observations may be similarly determined. If the receptacle is described as empty at the beginning of the storm, it should be indicated whether this is a matter of observation or a reasonable assumption. If the receptacle overflowed the time at which it was first observed spilling over is, of course, important.

(4) For precipitation caught in irregular-shaped receptacles, the most direct method of determining the depth is to divide the volume of water (in cubic inches) by the catchment area (in square inches) to obtain the depth (in inches). Because graduates marked in cubic inches are sometimes not available, the following equivalents are furnished here for convenience.

1 quart = 57.75 cubic inches
1 cup = 14.44 cubic inches
1 ounce = 1.805 cubic inches
1 liter = 61.02 cubic inches
1 cubic centimeter = .0610 cubic inches
1 centimeter = .392 inch
1 inch = 2.54 centimeters
1 pound = 27.7 cubic inches of water

For receptacles having a rolled edge, the catchment area is taken as extending to the ridge of the roll. In cases where volume or weight

SUPPLEMENTAL STORM SURVEYS (Cont.)

cannot be readily determined otherwise, it will be desirable to use the prismoidal formula to check the measured volume of water in containers with sloping sides, or to determine it originally. For this purpose, it is necessary to know the horizontal area at the bottom, at the half-depth of the water, at the surface of the water, and at the catchment level. The basic data usually required are the height, top dimension, bottom dimension, and depth of water. The volume is computed as

$$V = \left(\frac{A_B + 4A_M + A_T}{6}\right) d$$

where V is the volume (in cubic inches), A_B, A_M, and A_T the cross-section areas at the bottom, half-depth, and water surface, respectively (in square inches), and d is the depth of water (in inches). Here again the volume divided by the catchment area gives the true depth of precipitation.

(5) Sketches, showing dimensions, are very helpful in presenting, on the survey reports, the shape, direction, and amount of tilt of the receptacle, its location with respect to obstacles and shelter, etc., when appropriate. An obstacle may exert effects on precipitation for a horizontal distance twice or three times its height.

(6) Each interviewer should carry a steel tape or rule and appropriate graduates or measures. A spirit level is desirable and a camera may be helpful to round out the descriptions presented. However, the interviewers should be warned that photographs cannot replace the detailed sketches of the receptacles.

SNOW

.5 In collecting precipitation data, the Weather Bureau does not differentiate directly between snowfall and rain. Precipitation that falls as snow is either melted and measured as inches of water, or weighed and converted to inches of water. The snow cover is measured daily in inches of unmelted snow, but the data are not published. Precipitation data, including snow, are collected and published as outlined in Subparagraph 6.2.3A.

Snow Surveys

A. Since about 1936, "snow surveys" have become an important factor in forecasting seasonal runoff and in estimating the available water supply for irrigation, power, and domestic use. These snow surveys are made through the cooperative efforts of the Soil Conservation Service, Forest Service, National Park Service, Bureau of Indian Affairs, Geological Survey, Bureau of Reclamation, state experiment stations, state engineers, various irrigation associations, power companies, municipalities, and others. ★(See Chapter 1.4, Cooperative Agreements with other Agencies.)★ Determinations of depth and water content of the snow are made at various established locations within individual drainage basins. Usually four surveys are made each year, about February 1, March 1, April 1, and May 1. In the case of the Columbia River Basin, these surveys begin January 1. The results of these surveys may be obtained from the Soil Conservation Service each month in a bulletin, "Federal-State Cooperative Snow Surveys and Irrigation Water Forecasts," published soon after date of snow survey. The information contained in these bulletins is invaluable in studies of maximum snow cover and water potential for estimating snow floods. This is the only public source of actual snow cover data. The number of years of snow survey records in the western states hardly justify probability studies to determine maximum probable snow cover for a basin. These snow surveys, however, do serve as a guide for comparison with any estimated maximum probable basin snow cover.

Accuracy of Snow Data

B. Snow depth and snow runoff vary with latitude, elevation, and climatic conditions, and are influenced locally by the character of the topography and the vegetation. Because of its unstable character and various phases, snow

is extremely difficult to measure by any one method. The depth of snow cover and water content are the standards for measuring the quantity of snow. Accurate measurements of falling snow are equally hard to obtain due to the tendency of snowflakes to be deflected from the gages by wind currents. However, precipitation gage measurements are gradually increasing in accuracy because of careful studies of gage locations and development of windshields or screens for protecting gage orifices.

.6 Records of temperatures are collected mainly by the Weather Bureau at several types of stations. The principal types of stations and record forms are listed in Paragraph 6.2.3. Climatological Data, published monthly for individual states by ★the processing★ centers of the Weather Bureau, is the most common source of temperature records. It lists daily maximum and minimum temperatures for several (not all) stations, including cooperative observer records made on Form 1009. First-order stations publish a Monthly Meteorological (or Climatological) Summary, Form W.B. 1030, giving hourly temperatures (beginning in 1946), as well as daily extremes and means. ★Requests for data and information concerning temperature records should be directed to same offices as for rainfall records as described in Paragraph 6.2.3.★ TEMPERATURE

A. Following is a brief description of each type of temperature measurement and record: Type of Measurement & Record

(1) Form 1075, Thermograph Chart, is the chart as recorded by the thermograph which gives a continuous temperature record. It is made at all first-order stations, with hourly readings (on the hour) entered on Form 1014. These charts (Form 1075) are all filed at Washington, D.C. A few airway stations have thermographs and enter the records on Form 1130A. These records do not conform to the regular "on-the-hour" readings of Form 1014, but are made in accordance with teletype schedules. Many airway stations are not on a 24-hour basis, and therefore do not have continuous hourly readings.

(2) Form 1074, Hygrothermograph Chart, is a continuous dual record of humidity and temperature. The chart is filed at Washington, D.C.; however, hourly records are entered on Form 1014, which is filed at the station. This record is made at selected first-order stations only.

(3) Form 1009, Cooperative Observers' Meteorological Record, gives temperatures which are read from maximum and minimum thermometers near sunset each day.

(4) Form 1005, Cooperative Observers' Meteorological Record, is similar to Form 1009, except that it is used for corn and wheat region and cotton region stations where the observations are made in the morning, normally by 8:00 a.m., E.S.T.

B. The temperature records described in the preceding paragraphs may be used to obtain mean daily temperatures either from the daily maximums and minimums or preferably the continuous record chart if available. In snow-melt studies, the use of temperatures in day-degrees above 32° F. is a common practice. The meaning of day-degrees above 32° F. should not be confused with degree-days as defined by the Weather Bureau and published on Form 1030. In the latter case, it means the number of degree-days below 65° F. and is used as a basis for computing requirements for heating buildings. Wet-bulb, dry-bulb, and dewpoint temperatures as published on Form 1030 are useful in storm studies and storm transpositions. Use & Interpretation of Data

C. The estimation of temperature data is to be avoided if possible. In many flood studies it is not necessary to establish extensive area-temperature relations because of the comparatively small areas involved. A sufficient degree of accuracy may be obtained by assuming homogeneous or average Extension & Transposing of Data

Extension & Transposing of Data (Cont.)

temperatures over a small basin. Sometimes, however, the effect of elevation differentials in mountainous country makes it necessary to adjust for temperature-altitude relation. The rate of change of temperature with elevation under various conditions is as follows:

(1) The normal or average decrease of temperature with increase of altitude is about 3-1/2° F. per 1,000 feet up to about 25,000 feet above sea level (the tropopause).

(2) When air is lifted it can be assumed to expand dry adiabatically until it reaches its saturation point, after which it expands pseudoadiabatically. The dry adiabatic lapse rate is produced by a mixing process, such as convection in dry air. This air will cool at the rate of 5-1/2° F. per 1,000 feet.

(3) When air becomes saturated by lifting or by convection as in a cumulus cloud, the lapse rate within the cloud is called the moist adiabatic. This moist adiabatic temperature decrease is always less than the dry adiabatic of 5-1/2° F. per 1,000 feet, because as the air is cooled by expansion the latent heat of condensation is added back to the air and the net decrease of temperature is less. The moist adiabatic cooling rate is about 2° or 3° F. per 1,000 feet in the lower levels at temperatures above freezing. An adiabatic diagram is shown in Illustration 2.

RUNOFF .7 The Geological Survey of the United States Department of the Interior is the official source of the greater part of available streamflow data which appear in Water Supply Papers, published as a series of reports. Other Federal and state agencies which are a source of data on runoff comprise the following: Weather Bureau, Corps of Engineers, Soil Conservation Service, National Archives, International Boundary Commission,★state engineers, state universities and agricultural colleges, and municipalities. Several textbooks and miscellaneous publications also contain data on runoff.

Geological Survey

A. Water Supply Papers of the Geological Survey fall into several groups as follows:

(1) Reports of daily river discharge, appearing annually under the title Surface Water Supplies of the United States. This report is in 15 volumes, one for each of the 14 river basins or geographic units in the United States, convenient for reference and publication, and one for Hawaii. The area covered by each volume within the United States is shown on the map of District Boundaries and Principal Field Offices, Water Resources Branch, U. S. Geological Survey Appendix I to this chapter. The subject matter includes daily average flows, maximum and minimum peak flows, and annual flow volume, for the principal streams and many minor tributaries. Secondary instantaneous rain peak discharges have also been published since 1938, provided the peak exceeds the mean daily flow by 10 percent. Also included are description and type of each gaging station, period of record, an evaluation of the accuracy of the records, and a notation of any upstream regulation or diversion which would affect natural discharge. In Water Supply Papers prior to 1907, daily gage heights with rating tables, and monthly runoff were published. For the period 1907 - 1915, gage heights and mean daily discharges were both published.

(2) Compilations of discharge records by basins or states, in which all records in a geographic unit for a series of years are compiled.

(3) Reports on the quantity, chemical quality, and availability of groundwater.

(4) Reports on the chemical quality of water from specified sources, with special reference to their utility in agriculture and industry.

is extremely difficult to measure by any one method. The depth of snow cover and water content are the standards for measuring the quantity of snow. Accurate measurements of falling snow are equally hard to obtain due to the tendency of snowflakes to be deflected from the gages by wind currents. However, precipitation gage measurements are gradually increasing in accuracy because of careful studies of gage locations and development of windshields or screens for protecting gage orifices.

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Extension & Transposing of Data (Cont.)

temperatures over a small basin. Sometimes, however, the effect of elevation differentials in mountainous country makes it necessary to adjust for temperature-altitude relation. The rate of change of temperature with elevation under various conditions is as follows:

(1) The normal or average decrease of temperature with increase of altitude is about 3-1/2° F. per 1,000 feet up to about 25,000 feet above sea level (the tropopause).

(2) When air is lifted it can be assumed to expand dry adiabatically until it reaches its saturation point, after which it expands pseudoadiabatically. The dry adiabatic lapse rate is produced by a mixing process, such as convection in dry air. This air will cool at the rate of 5-1/2° F. per 1,000 feet.

(3) When air becomes saturated by lifting or by convection as in a cumulus cloud, the lapse rate within the cloud is called the moist adiabatic. This moist adiabatic temperature decrease is always less than the dry adiabatic of 5-1/2° F. per 1,000 feet, because as the air is cooled by expansion the latent heat of condensation is added back to the air and the net decrease of temperature is less. The moist adiabatic cooling rate is about 2° or 3° F. per 1,000 feet in the lower levels at temperatures above freezing. An adiabatic diagram is shown in Illustration 2.

RUNOFF .7 The Geological Survey of the United States Department of the Interior is the official source of the greater part of available streamflow data which appear in Water Supply Papers, published as a series of reports. Other Federal and state agencies which are a source of data on runoff comprise the following: Weather Bureau, Corps of Engineers, Soil Conservation Service, National Archives, International Boundary Commission,★state engineers, state universities and agricultural colleges, and municipalities. Several textbooks and miscellaneous publications also contain data on runoff.

Geological Survey

A. Water Supply Papers of the Geological Survey fall into several groups as follows:

(1) Reports of daily river discharge, appearing annually under the title Surface Water Supplies of the United States. This report is in 15 volumes, one for each of the 14 river basins or geographic units in the United States, convenient for reference and publication, and one for Hawaii. The area covered by each volume within the United States is shown on the map of District Boundaries and Principal Field Offices, Water Resources Branch, U. S. Geological Survey Appendix I to this chapter. The subject matter includes daily average flows, maximum and minimum peak flows, and annual flow volume, for the principal streams and many minor tributaries. Secondary instantaneous rain peak discharges have also been published since 1938, provided the peak exceeds the mean daily flow by 10 percent. Also included are description and type of each gaging station, period of record, an evaluation of the accuracy of the records, and a notation of any upstream regulation or diversion which would affect natural discharge. In Water Supply Papers prior to 1907, daily gage heights with rating tables, and monthly runoff were published. For the period 1907 - 1915, gage heights and mean daily discharges were both published.

(2) Compilations of discharge records by basins or states, in which all records in a geographic unit for a series of years are compiled.

(3) Reports on the quantity, chemical quality, and availability of groundwater.

(4) Reports on the chemical quality of water from specified sources, with special reference to their utility in agriculture and industry.

(5) Reports on important topics or unusual phenomena, such as floods, droughts, and fluctuations in groundwater stages. (See Page 10A of Appendic I for a list of Geological Survey Water Supply Papers pertaining to flood data in the 17 western states.)

(6) Reports on the present and possible future utilization of rivers.

B. The Weather Bureau, U. S. Department of Commerce, publishes annually a volume entitled River Stages, containing the records of river stages observed at a large number of stations maintained primarily in connection with flood forecasting. ★Forecasts of critical river stages on major rivers are released by the river forecast centers and forecasts of water year flows in selected rivers are published in the spring by the water supply forecast centers. Lists of Weather Bureau River Forecast Centers and Water Supply Forecast Centers west of the Mississippi River are given in Appendix I to this chapter.★ — Weather Bureau

C. The Corps of Engineers and the Mississippi River Commission, Department of the Army, publish annual reports of stages and discharges of the Mississippi River and tributaries, and from time to time, compilations of such records for selected river stations or for particular periods of time. The Corps publishes many reports on river and harbor improvement projects and reports on floods or features related to flood control and navigation. Such reports are published in the Annual Report of the Chief of Engineers and in Congressional Documents, of which perhaps the most noteworthy is the series of reports prepared in response to House Document 308, 67th Congress, 1st session. In this series of reports, the Corps was authorized and directed to report on many specified rivers of the country with respect to navigation, flood control, water power, and irrigation. These "308" reports cover the principal rivers of the country, except those in the drainage basins of the Colorado River and Great Salt Lake. A great deal of data on storms and floods may be found in hydrological appendices to these reports which should be obtained and perused for such information. A map showing divisions and districts of the Corps of Engineers is included in Appendix I to this chapter. — Corps of Engineers

D. The Soil Conservation Service of the United States Department of Agriculture has made numerous hydrologic studies for small watersheds, in connection with research and in cooperation with state experimental stations. These studies involved measurements of rainfall and runoff on forest grazing, and cultivated lands for the specific purpose of determining amounts of runoff from rainfall. Records of rainfall and runoff are published in detail in Hydrologic Studies, Compilation of Rainfall and Runoff from the Watersheds of the _____ Agricultural Experiment Station. The
(State)
administrative regions of the Soil Conservation Service are shown in Appendix I to this chapter. — Soil Conservation Service

E. National Archives has records observed by the Signal Corps prior to the transfer of weather observations to the Weather Bureau on October 1, 1890. These can be obtained on microfilm through the Washington D. C. offices. — National Archives

F. ★The International Boundary and Water Commission publishes annual reports of streamflow along the border between the United States and Mexico. International gage stations on the border between the United States and Canada are maintained jointly under the Boundary Waters Treaty. The Geological Survey publishes the records.★ — International Boundary Commission

G. Publication of river records by states is widely diverse, both as to substance and form. Many states do not publish records of river discharge, but rely on the publications of the Geological Survey to serve their needs. Other states publish compilations and summary reports, and a few still publish annual — States

reports containing fairly complete records of river discharge. Many old records, however, are contained in state reports, some of which are not available elsewhere.

State Universities

H. Several state universities maintain well-equipped hydraulic laboratories and publish the results of hydraulic experiments and studies made therein. The scope and availability of state university reports can be learned only by correspondence with the respective state officials. State agricultural colleges, particularly those with well-developed engineering schools, frequently have data that are useful in making flood studies. A list of universities and state agricultural colleges is given in Appendix I of this chapter.

Municipalities

I. Municipalities and public utility companies often collect runoff records for their own information. These data are usually not published, and it is therefore necessary to contact the proper representatives in order to procure such records. Interpretations of these records have to be made by the interested party investigating them.

Other Discharge Data

J. Several lists of maximum recorded discharges for the major streams in the United States have been published. Some of these publications are given in Appendix I to this chapter.

Slope-Area Measurements

K. Special and miscellaneous measurements of stream runoff are often made under various conditions where there is need for such records. Under this category are slope-area determinations of maximum discharges of flood flow and miscellaneous measurements of streamflow to compute rating curves or estimate runoff volumes where no gage record is available. (See the Bureau of Reclamation "Manual for Measurement of Irrigation Water" and Geological Survey Water Supply Paper 888 "Stream-Gaging Procedure.") The slope-area method may be used in the determination of mean velocity and in estimating total discharge for any stages at which currentmeter measurements are not possible or practicable, but the greatest value of this method lies in the means it affords of ascertaining the magnitudes of peak flows after such flows have passed. If correlated with peak gage height at the station gage, such determinations are valuable in helping to define extensions of rating curves above the highest available currentmeter discharge measurements. During maximum flows, it is impracticable to attempt currentmeter measurements because of debris carried by the stream, or the lack of a cable or bridge from which to make the measurements.

Units of Discharge & Volume

L. Since water losses and runoff vary greatly during different seasons of the year, it has been found convenient to use a "water year" rather than a calendar year for studies in hydrology. The year can be divided into three periods called the storage, growing, and replenishing periods. The exact limits of these periods vary in different parts of the country. The Geological Survey, in its "Water Supply Papers," is now using a water or climatic year beginning with October 1 for the annual report. Most other agencies and collectors of hydrologic data use this period for the sake of consistency. Units of measurement are discussed in detail in Part 2 of this Volume and in the Bureau "Manual for Measurement of Irrigation Water." Units of discharge and volume used by the Bureau in flood hydrology studies are as follows:

(1) In the United States the record of flow of the surface streams is commonly made in terms of the mean daily discharge, expressed in cubic feet per second (cfs). Such a record is ordinarily obtained by means of a record of stage which is converted into a record of discharge at one or two general types of stations.

(2) Another unit of discharge common in this country is "second-feet per square mile," which is used for expressing the average rate of discharge from a basin and is also valuable for comparison of discharge among rivers in the same region.

Units of Discharge & Volume (Cont.)

(3) The "miner's inch," which in former years was quite widely used in the western mining states, is defined as the quantity of water that will be discharged through a sharp-edged, 1-inch-square orifice under a fixed head, which varies among the states. One cfs equals 38.4 miner's inches in Colorado, 40 miner's inches in California, and 50 miner's inches in Idaho; other western states use one or another of these three definitions. Because of the lack of uniformity of this unit, it has been largely displaced by the cfs measurement.

(4) The unit of volume commonly employed is the "acre-foot" which is the quantity of water required to cover 1 acre to the depth of 1 foot, or equivalent to 43,560 cubic feet.

Accuracy of Discharge Data

M. The accuracy of the records of discharge will be governed by the accuracy of the recorded stage and of the conversion of the stage to discharge. The reliability of the conversion of the record of stage into the record of discharge is affected by the stability of the stage-discharge relation, by the extent to which the station rating curve is well-defined, by discharge measurements, by the magnitude and duration of backwater, by the rapidity and frequency of fluctuations in stage and discharge, by the effect of ice, and also by the method and accuracy of the application of the station rating to the record of stage. The average anticipated annual variations of error in records of daily discharge obtained by stream gaging range from less than 1 percent for the best stations with stable controls and continuous records of stage, to 5 or 10 percent for nonrecording stations with shifting controls, rapid and frequent fluctuations in stage and discharge, and inadequate information in the form of discharge measurements for properly delineating the stage-discharge relation. For stations with badly shifting controls, the relative accuracy of the records of discharge generally varies directly with the amount of effort put forth in obtaining frequent well-spaced discharge measurements, particularly at times of critical stages. The stage-discharge relation is based on discharge measurements, and the more variable this relation may be, the greater will be the number of discharge measurements needed to define properly the magnitude and duration of the changes therein.

Careful consideration should be given to the accuracy of slope-area measurements made from unknown sources of data and by other than authentic agencies. An investigation should be made of the circumstances under which field surveys and computations of each measurement were made. For instance, cases are on record where the high-water marks, considered in computing the peak discharge from slope-area measurements were caused by a break in a fill or a dike releasing a large amount of water in storage. Such cases cause computed peak discharge to be in excess of the true natural values and should not be used in envelope curve studies. Careful check should also be made on slope-area computations made by other than experienced personnel to reveal any questionable assumption as to coefficient of roughness or in computing the energy gradient.

Estimating Missing Data

N. Estimates of rates of discharge and/or runoff volumes at a desired location, where there are no records available, may be made by correlation of discharge and runoff records at other stations near the site with their respective drainage areas. Best results are obtained when records are available, both above and below the desired location on the same stream. In such cases estimated records may be derived by plotting simple correlations between rates of discharge and/or runoff volumes and drainage areas on logarithmic paper and selecting the discharge or runoff volume for the area in question from a straight line relation between the two known points. If, however, there is only one gaging station on the stream, the peak discharge or volume of runoff may be estimated for other points on the stream by assuming that peak discharge and/or volume vary directly with some exponential power of the drainage areas. Although the correct exponent to be used for any particular area is questionable, an exponent of 0.5 as derived by A. F. Myer for correlating peak discharge with area is probably the most

Estimating Missing Data (Cont.)

widely used. Another method of estimating the runoff-area relationship is to use the envelope curve (see Chapter 6.3) which is derived by plotting rates of discharge or volumes against drainage areas for streams in the vicinity in which the record is desired. The slope of this curve can then be used to estimate the relationship between runoff and drainage areas. Caution should be used in applying this method to records too far removed from the location of the station for which runoff information is desired. Records may also be estimated by simple computations if enough actual records are available to make such a procedure possible. Here it would be necessary to know the runoff from major tributary areas above the point in question. The flow at points along the main stream may then be estimated by combining recorded flows from the tributaries.

Momentary Hydrographs

O. For detailed analysis of storm runoff, it is desirable to obtain from the Geological Survey's district office the actual hydrograph, stage versus time, of streamflow at the stations under study. A print of the rating curve or a rating table is also necessary in order to transpose this stage versus time hydrograph into a hydrograph of runoff in cfs versus time. The area under this hydrograph can then be measured with a planimeter, converted to acre-feet, and used as the actual volume of runoff for the period under consideration.

OTHER METEORO-LOGICAL DATA

.8 Several types of other data are available for detailed analysis of storm-runoff features. Of these data some are of particular interest to the hydrologist in determining the maximum probable flood. The most important are soil, moisture, vegetal cover, and infiltration capacities. Upper air temperatures and pressures are available for most storms of major importance during the last few years. Surface dewpoints, wind velocities, and wind directions are also available and of special interest to the meteorologists in storm studies relative to determining the maximum possible storm over a given basin. Most of these storm data are available at first-order or airway stations of the Weather Bureau. Some of the data are published on W. B. Form 1030, a monthly individual Weather Bureau station publication. Soil surveys are outlined by general soil maps published in the Atlas of American Agriculture for 1936 and by detailed soil studies such as Soil Survey Reports by the United States Department of Agriculture. Various types of data pertaining to climate, soils, geology, snow, and floods are given in Forest Service publications. A list of these publications is given in the United States Department of Agriculture Bulletin 364, "A Selected Bibliography of North American Forestry." A map and a tabulation in Appendix I to this chapter give the Forest Service Research Central and Field Station. The "308" reports, mentioned in Subparagraph 6.2.7C, in addition to discharges, have information on geology, soils, temperature, wind, and other factors that are useful in making flood studies. The Soil Conservation Service has different types of data of which one of the most valuable, from the standpoint of flood studies, is the experimental data pertaining to infiltration and runoff. Many state agricultural colleges and universities have conducted experiments and collected data on various phases of hydrology.

SEDIMEN-TATION

.9 The amount of suspended sediments have been measured in some of the principal rivers such as the Mississippi and Rio Grande since before 1900. The Governmental agencies that became actively engaged in collecting sedimentation data at an early date are: (1) Corps of Engineers, Department of the Army, (2) Geological Survey, (3) Department of Agriculture, and (4) Bureau of Reclamation. Since 1879 the Corps of Engineers has been taking suspended sediment samples on the Mississippi River, and since 1929 have been active on the Missouri River and its tributaries. The Geological Survey started investigations on the Rio Grande in 1889, and in 1906 were active on many other rivers of the Western United States. The Department of Agriculture in 1900 began a sampling program on the Brazos and Wichita Rivers in Texas. The Bureau of Reclamation has taken measurements on the Colorado River since 1909. In 1934 the Soil Conservation Service began assuming the Department of Agriculture's role in sedimentation, and at the present time, is one of the most active Government agencies in this specialized field. The results of investigation by these agencies are to

be found in the following publications: (1) Report of Chief of Engineers, United States Army, and the United States Waterways experimental Station, Vicksburg, Mississippi; (2) Geological Surveys Water Supply Papers; (3) United States Department of Agriculture technical bulletins; (4) state college bulletins; and (5) in various special reports. SEDIMENTATION (Cont.)

Basic data on sedimentation is not as yet organized, compiled, or collected in any one central office. It is planned that the Geological Survey will in the future publish all data on sediment sampling from streams and rivers regardless of the agency doing the sampling and analyzing. ★ The Subcommittee on Sedimentation of the Federal Inter-Agency River Basin Committee has compiled an "Inventory of Published and Unpublished Sediment Load Data in the United States" (Sedimentation Bulletins Nos. 1 and 4). This represents a most important source of information for those engaged in the field of sedimentation. This Subcommittee has also published an "Annotated Bibliography on Sedimentation" (Sedimentation Bulletin No. 2). The Soil Conservation Service at Washington, D.C. has perhaps the largest reference library on sedimentation. Recent development pertaining to both equipment and methods of sampling and analyzing are given in a series of reports published by the St. Paul district office of the Corps of Engineers. The contents of the reports, which represent the cooperative efforts of several Governmental agencies and the Subcommittee on Sedimentation, working with the University of Iowa and the University of Minnesota, are very enlightening and contain many references. ★

.10 The following is a statement of policy concerning the use by Bureau of Reclamation personnel of regional repositories of the Weather Bureau and the Geological Survey for precipitation, streamflow, and related data: CENTRALIZED REPOSITORIES

A. The Federal Inter-Agency River Basin Committee has recommended that the individual agencies represented on the Committee adopt the policy of using regional repositories of the Weather Bureau and the Geological Survey for precipitation, streamflow, and related data.

B. The Committee recommended that meteorological data collected by other agencies be filed by the Weather Bureau. These data would probably consist primarily of precipitation and temperature data, although other types of meteorological data such as those related to wind, evaporation, etc., would be accepted, even though these data are not likely to be available in quantity. The repositories for precipitation records from ★recording gages and all other types of meteorological data will be the appropriate state section centers of the Weather Bureau.★

C. Similarly, the Committee recommended that streamflow and related data collected by other agencies be filed with the Geological Survey. These data might include the following general types: (1) currentmeter discharge measurements; (2) miscellaneous flood discharge determinations by basic methods including slope area, contracted opening, and flow over dams; (3) lake or reservoir elevations and contents; (4) mean daily discharges of streams (including canals); (5) daily stream elevations or gage height records where adequate ratings are available or may be determined so that conversion to streamflow could be made; (6) groundwater stages, well logs, and discharge of springs; (7) chemical analyses of both surface water and groundwater; and (8) data concerning water utilization. The repository for streamflow and related data will be the appropriate district office of the Geological Survey. In some cases, where the information is of broad significance or for other good reasons, the repository for selected streamflow records and related data will be the Washington office of the Geological Survey.

D. The Weather Bureau and Geological Survey offices will accept, file, and make available to the general public the records submitted to them. The data should either be the original field records in a form suitable for filing or a listing that can be reproduced by normal means; i.e., blueprint, etc.

CENTRALIZED REPOSITORIES (Cont.)

Microfilm records would be acceptable. The Weather Bureau and the Geological Survey reserve the right to accept for filing only those data considered to be of adequate public value, hence advance determination of the acceptability of the data is advisable before actual transmission. Proper credit would be given to the individual or agency responsible for the collection or compilation whenever such data were consulted or disseminated.

E. The Committee's recommendations conform in general with past Bureau practice for certain of these data, this practice having been on a voluntary basis. The Committee's recommendations are therefore adopted as Bureau policy, to be carried out to the fullest extent considered commensurate with Bureau interest. Field offices are requested to furnish original data, where feasible, to the appropriate office of the Weather Bureau and the Geological Survey. If doubt exists as to the proper office for filing, ★ write the Commissioner, attention 759, requesting that the Washington offices of those agencies be asked to designate the proper one. ★ Field offices of the two agencies have been furnished copies of this statement of policy.

STORM PRECIPITATION SURVEY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Region 7
Republican River District
(Local Office)

STORM PRECIPITATION SURVEY

Date 5/16/47

Storm Period April 27, 1947 Interviewer E. Dixson

General Location Yuma County, Colorado, 12 miles due west of Vernon

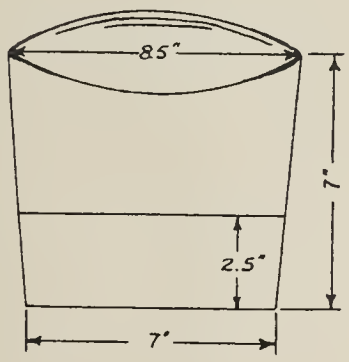
Township 1 S Range 46 W Section 28 1/4 Section NW Elevation approx 3800'

Observer Marvin Tuell Address Vernon, Colorado

PRECIPITATION

Begun		Ended		Measured			True
Date	Time	Date	Time	Date	Time	Depth	Depth
4/27	3:30 P MST	4/27	DN _ST	4/28	6a MST	2.5"	1.8"
	_ST		_ST		_ST		
	_ST		_ST		_ST		
	_ST		_ST		_ST		
	_ST		_ST		_ST		

Describe receptacle and exposure; give details if: not level, sides not vertical (sketch), not empty before storm, not watertight, overflowed, poorly exposed; give distance from, and heights of trees and buildings. Quote observer on intense precipitation, beginnings, endings and amounts; form of precipitation, etc. Give further comment on reliability, ground condition, crops, etc.



Pail level, in yard, 50 feet south of tree and road. Burst of heavy rain with hail, 4:30 pm to 5:20 pm.
Grass very short: 70% pasture, 15% wheat

$$V = \frac{A_B + 4A_M + A_T}{6} d$$

$$V = \frac{\pi}{4}\frac{6}{6}(49 + 211.4 + 56.9)2.5$$

$$V = 33.1\pi$$

$$A = \frac{\pi}{4} 8.5^2 = 18.1\pi$$

$$A_B = \frac{\pi}{4} 7^2$$

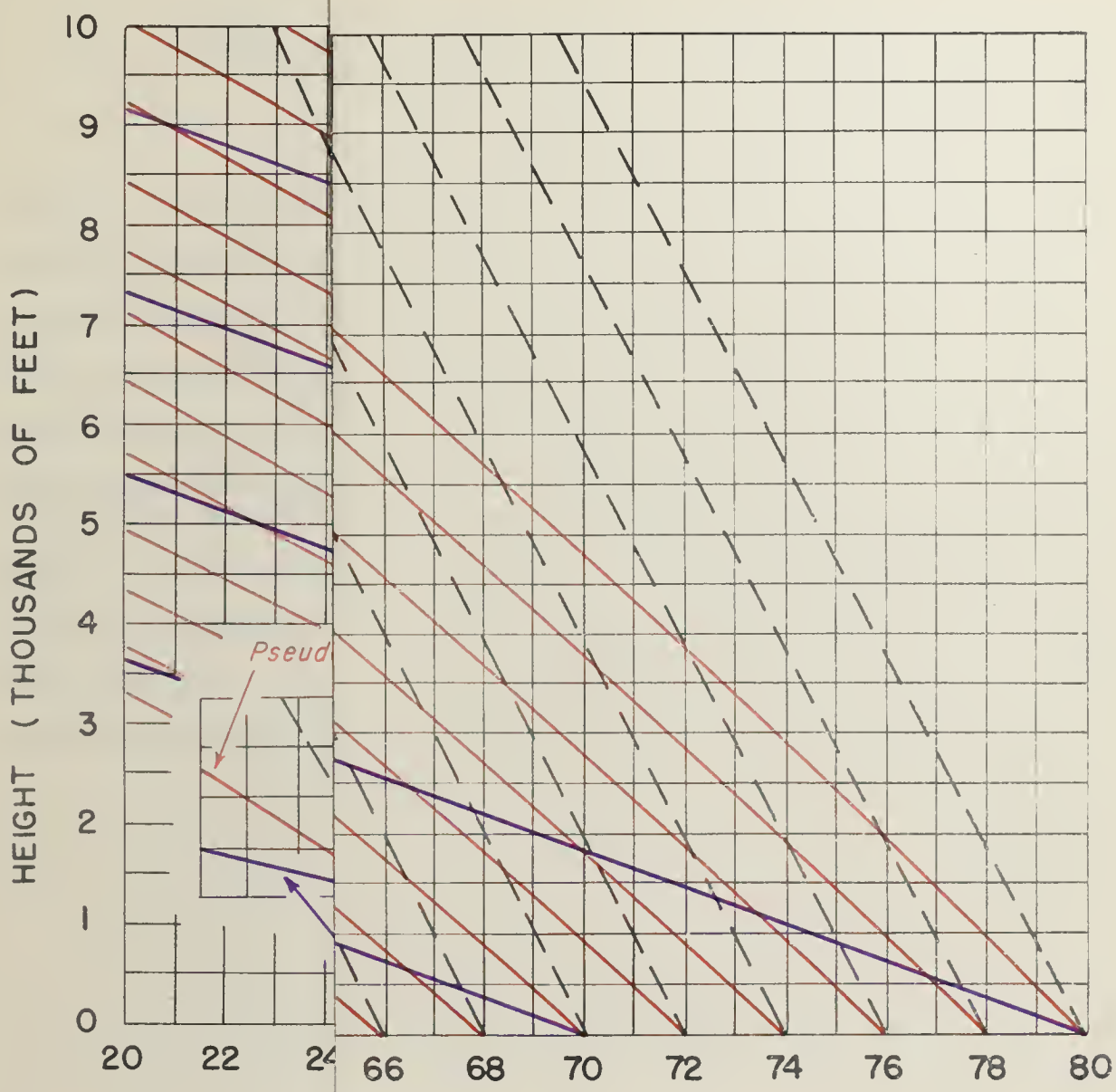
$$A_M = \frac{\pi}{4} 7.27^2$$

$$A_T = \frac{\pi}{4} 7.54^2$$

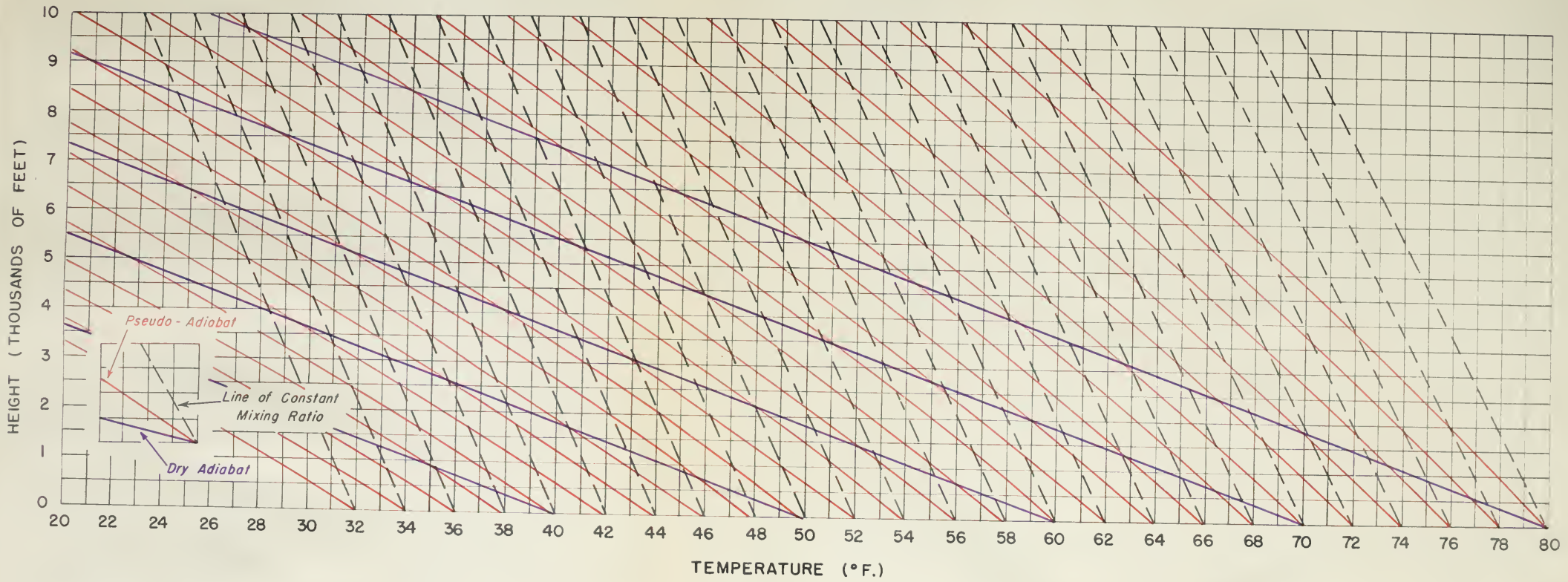
$$\text{True Depth} = \frac{V}{A} = \frac{33.1}{18.1} = 1.83 \text{ in.}$$

DKB 7-22-48

HD-39 (Experimental)



PSEUDO-ADIABATIC DIAGRAM
ADAPTED FOR DEW-POINT
AND WET BULB REDUCTIONS



Note: Traced from Weather Bureau Pseudo-Adiabatic Diagram.

PSEUDO-ADIABATIC DIAGRAM ADAPTED FOR DEW-POINT AND WET BULB REDUCTIONS

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION MANUAL

Volume IV--Water Studies

Part 6--Flood Hydrology

Appendix I--Sources of Hydrologic Data--to Chapter 6.2

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CHAP. 6.2 BASIC HYDROLOGIC DATA
APPENDIX I SOURCES OF HYDROLOGIC DATA

SUMMARY OF MAJOR SOURCES

Sources of rainfall data--(published)

1. Monthly Climatological Data (Weather Bureau).
2. Daily Weather Map (Weather Bureau).
3. Monthly Weather Review (Weather Bureau).
4. Hydrologic Bulletin (Weather Bureau--Hydrologic Unit).
5. Form 1030--Monthly Meteorological Summary (Weather Bureau first order station).

Sources of rainfall data--(unpublished)

6. Form 1130A (Weather Bureau Airway Station).
7. Form 1001--Original Monthly Record of Observation (Weather Bureau).
8. Form 1005--Cooperative Observers' Meteorological Record (Weather Bureau).
9. Form 1006--Monthly Report of River Rainfall Station (Weather Bureau).
10. Form 1009--Cooperative Observers' Meteorological Record (Weather Bureau).
11. Form 1014--Daily Local Record (Weather Bureau first order station).
12. Form 1017--Wind Velocity and Direction, Rain, and Sunshine (Weather Bureau).

Record of evaporation and meteorological conditions (Weather Bureau)

13. Form 1024 and Form 1024 (a)--Monthly Record of Evaporation and Meteorological Conditions--(unpublished).
14. Monthly Climatological Data--(published).

Sources of snowfall and snow accumulation data--(published)

15. Federal-State Snow Surveys and Irrigation Water Forecast by Division of Irrigation, Soil Conservation Service, U. S. Department of Agriculture and State Experiment Station.
16. Above-listed Weather Bureau rainfall data. (These usually give current snow conditions.)

Sources of temperature data

17. Climatological Data (Weather Bureau).
18. Monthly Meteorological Summary--Form WB-1030 (Weather Bureau).
19. Daily Weather Map (Weather Bureau).
20. Monthly Weather Review (Weather Bureau).
21. Form 1075--Thermograph Chart (Weather Bureau)--(unpublished).
22. Form 1074--Hygrothermograph Chart (Weather Bureau).
23. Form 1009--Cooperative Observers' Meteorological Record (Weather Bureau)--(unpublished).

Sources of runoff data

24. Water Supply Papers (Geological Survey, U. S. Department of Interior)--(published).
25. Water stage recorder chart and station rating curves and tables (Geological Survey)--(unpublished).
26. Maximum discharges at stream-measurement stations through September 30, 1938--Water Supply Paper 847--Geological Survey.
27. Average and Maximum River Discharges, Handbook of Applied Hydraulics by Davis, McGraw-Hill, 1942, Table 8, pp. 64-105.
28. Unusual Flood Peaks, United States and Foreign Rivers, Engineering for Dams by Creager, Justin, and Hinds, Wiley and Sons, 1945, Vol. I, pp. 101-124, Table 1.

Sources of sedimentation data

29. Regular, special and miscellaneous reports of the following United States Agencies:

    a. Corps of Engineers
    b. Geological Survey
    c. Soil Conservation Service
    d. Bureau of Reclamation.

WEATHER BUREAU OFFICES WEST OF MISSISSIPPI RIVER

Name of Office	Address
Region 3 (Regional Office, 1400 U. S. Courthouse, Chicago, Illinois)	
Minnesota (Section Center, Minneapolis)	
Duluth, CO	WBO, Duluth 6, Minn.
Duluth, AP	WBAS, Duluth, Minn.
*Grand Marais	WBO, Grand Marais, Minn.
International Falls	WBO, International Falls, Minn.
Minneapolis, CO	WBO, Minneapolis 1, Minn.
Minneapolis, AP	WBAS, Minneapolis 6, Minn.
Rochester	WBO, Rochester Airport, Rochester, Minn.
St. Cloud	WBO, St. Cloud, Minn.
St. Paul	WBO, St. Paul 1, Minn.
North Dakota (Section Headquarters, Bismarck)	
Bismarck	WBO, Bismarck, N. Dak.
Devils Lake	WBO, Devils Lake, N. Dak.
Fargo	WBO, Box 827, Fargo, N. Dak.
Williston	WBO, Williston, N. Dak.
Region 4 (Regional Office, Fort Worth, Texas)	
Arkansas (Section Center, Little Rock)	
*Brinkley	WBO, Brinkley, Ark.
Fort Smith	WBO, Fort Smith, Ark.
Little Rock	WBO, Box 1819, Little Rock, Ark.
Texarkana	WBO, Box 1018, Texarkana, Ark.-Tex.
Louisiana (Section Center, New Orleans)	
Baton Rouge	WBO, Box 1347, Baton Rouge, La.
Burrwood	WBO, Box 75, Burrwood, La.
Lake Charles	WBO, Box 572, Lake Charles, La.
New Orleans, CO	WBO, 317 Post Office Building, New Orleans 12, La.
New Orleans, AP	WBAS, Moisant International Airport, New Orleans, La.

*Office has recently been discontinued.
Abbreviations:
WBO, Weather Bureau Office
WBAS, Weather Bureau Airport Station
CO, City Office
AP, Airport

CHAP. 6.2 BASIC HYDROLOGIC DATA
APPENDIX I SOURCES OF HYDROLOGIC DATA

Name of Office	Address
New Orleans (FAWS)	Flight Advisory Weather Service, Box 614, New Orleans, La.
New Orleans (Coding Unit)	WBO, Coding Unit, New Orleans Airport, New Orleans 17, La.
Shreveport	WBO, Box 1571, Shreveport 94, La.
Oklahoma (Section Center, Oklahoma City)	
Oklahoma City, CO	WBO, Northwest Station, Box C, Oklahoma City 6, Okla.
Oklahoma City, AP	WBAS, Route 6, Box 365A, Oklahoma City, Okla.
Tulsa, AP	WBAS, Box 37, Dawson, Okla.
Tulsa, CO	WBO, Tuloma Building, Tulsa 3, Okla.
Waynoka	WBO, Box 788, Waynoka, Okla.
Texas (Section Center, Houston)	
Abilene	WBO, Municipal Airport, Abilene, Tex.
Amarillo	WBO, Amarillo, Tex.
Austin	WBO, Austin 22, Tex.
Big Spring	WBO, Box 1549, Big Spring, Tex.
Brownsville	WBO, Box 1391, Brownsville, Tex.
Corpus Christi	WBO, Route 3, Box 494, Corpus Christi, Tex.
Dallas	WBO, Dallas 9, Tex.
Del Rio	WBO, Del Rio, Tex.
El Paso	WBO, El Paso, Tex.
Fort Worth (Regional Office)	Weather Bureau Regional Office, Fort Worth 2, Tex.
Fort Worth, AP	WBAS, Meacham Field, Fort Worth, Tex.
Galveston, CO	WBO, Galveston, Tex.
Galveston, AP	WBAS, Box 240, Galveston, Tex.
Houston, CO	WBO, Box 4089, Houston 14, Tex.
Houston, AP	WBAS, Houston 12, Tex.
Laredo	WBO, Box 578, Laredo, Tex.
Lubbock	WBO, Route 3, Lubbock, Tex.
*Mineola	WBO, Mineola, Tex.
Palestine	WBO, Box 479, Palestine, Tex.
Pampa	WBO, Box 1697, Pampa, Tex.
Port Arthur, CO	WBO, Box 368, Port Arthur, Tex.
Port Arthur, AP	WBAS, Box 636, Nederland, Tex.
San Antonio	WBO, San Antonio, Tex.
Swan Island, W. I.	WBO, Swan Island, W. I., % WBRO, Fort Worth 2, Tex.
*Tyler	WBO, Box 838, Tyler, Tex.
Waco	WBO, Route 1, Box 57, Waco, Tex.
Wichita Falls	WBO, Box 117, Wichita Falls, Tex.
New Mexico (Section Center, Albuquerque)	
Albuquerque	WBO, Albuquerque, N. Mex.
Clovis	WBO, Box 975, Clovis, N. Mex.
Raton	WBO, Raton, N. Mex.
Roswell	WBO, Roswell, N. Mex.
*Tucumcari	WBO, % CAA Airway Comm. Station, Box 818, Tucumcari, N. Mex.
Region 5 (Regional Office, Kansas City, Missouri)	
Iowa (Section Center, Des Moines)	
Burlington	WBO, Burlington, Iowa

*Office has recently been discontinued.

CHAP. 6.2 BASIC HYDROLOGIC DATA
APPENDIX I SOURCES OF HYDROLOGIC DATA

Name of Office	Address
+Davenport	WBO, Davenport, Iowa
Des Moines, CO	WBO, Box 716, Des Moines 3, Iowa
Des Moines, AP	WBAS, Des Moines 15, Iowa
Dubuque	WBO, Dubuque, Iowa
Sioux City	WBO, Sioux City 3, Iowa
Missouri (Section Center, St. Louis)	
Columbia, CO	WBO, Columbia, Mo.
Columbia, AP	WBAS, Route 6, Columbia, Mo. (Send adm. corres. to city office.)
Kansas City (Regional Office)	Weather Bureau Regional Office, 301 U. S. Courthouse, Kansas City, Mo.
Kansas City (Hydroclimatic Section)	WBO, Hydroclimatic Section, 802 Fidelity Building, Kansas City 6, Mo.
Kansas City, AP	WBAS, Kansas City 6, Mo.
Kansas City (River Forecast Center)	Weather Bureau River Forecast Center, 810 Fidelity Building, Kansas City 6, Mo.
St. Joseph, CO	WBO, Box 665, St. Joseph 1, Mo.
St. Joseph, AP	WBAS, % CAA Airway Comm. Station, Box 948, St. Joseph, Mo. (Send adm. corres. to city office.)
St. Louis, CO	WBO, St. Louis 1, Mo.
St. Louis, AP	WBAS, Lambert Field, St. Louis 21, Mo.
Springfield	WBO, Box 125, Main Post Office, Springfield, Mo.
Vichy	WBO, % CAA Airway Comm. Station, Vichy Army Air Field, Vichy, Mo.
Kansas (Section Center, Topeka)	
Concordia	WBO, Concordia, Kansas
Dodge City	WBO, Dodge City, Kansas
Garden City	WBO, % CAA Airway Comm. Station, Box 425, Garden City, Kansas
Goodland	WBO, Goodland, Kansas
Topeka	WBO, Topeka, Kansas
Topeka, AP	WBAS, Phillip Billard Airport, Topeka, Kansas
Wichita	WBO, Wichita 1, Kansas
Nebraska (Section Center, Lincoln)	
Grand Island	WBO, % CAA Airway Comm. Station, Box 568, Grand Island, Nebr.
Lincoln, CO	WBO, Lincoln 1, Nebr.
Lincoln, AP	WBAS, % CAA Airway Comm. Station, Box 386, Lincoln, Nebr. (Send adm. corres. to city office.)
Norfolk	WBO, City Auditorium, Norfolk, Nebr.
North Platte, CO	WBO, North Platte, Nebr.
North Platte, AP	WBAS, Box 818, North Platte, Nebr.
Omaha	WBO, Omaha 2, Nebr.
Valentine	WBO, Valentine, Nebr.
South Dakota (Section Center, Huron)	
Huron, CO	WBO, Huron, S. Dak.
Huron, AP	WBAS, Huron, S. Dak.

+This station is administratively in Region 3.

Name of Office	Address
Rapid City	WBO, Rapid City, S. Dak.
Sioux Falls	WBO, Box 309, Sioux Falls, S. Dak.
Wyoming (Section Center, Cheyenne)	
Casper	WBO, Box 1372, Casper, Wyo.
Cheyenne	WBO, Cheyenne, Wyo.
Lander	WBO, Lander, Wyo.
Rock Springs	WBO, Rock Springs, Wyo.
Sheridan	WBO, Sheridan, Wyo.
Colorado (Section Center, Denver)	
Alamosa	WBO, Alamosa, Colo.
Denver, CO	WBO, Denver 1, Colo.
Denver, AP	WBAS, Denver 7, Colo.
Grand Junction	WBO, Grand Junction, Colo.
Pueblo	WBO, Pueblo, Colo.

Region 6 (Regional Office, Los Angeles, California)

Utah (Section Center, Salt Lake City)	
Coalville	WBO, Coalville, Utah
Modena	WBO, Modena, Utah
Ogden	WBO, Box 867, Ogden, Utah
Salt Lake City, CO	WBO, Salt Lake City 1, Utah
Salt Lake City, AP	WBAS, Salt Lake City 3, Utah
Arizona (Section Center, Phoenix)	
Flagstaff	WBO, Post Office Building, Flagstaff, Ariz.
Phoenix, CO	WBO, Box 308, Phoenix, Ariz.
Phoenix, AP	WBAS, Route 9, Box 15, Phoenix, Ariz.
Prescott	WBO, Box 1031, Prescott, Ariz.
Tucson	WBO, Box 4126, University Station, Tucson, Ariz.
Winslow	WBO, Winslow, Ariz.
Yuma	WBO, Yuma, Ariz.
Nevada (Section Center, Salt Lake City, Utah)	
Elko	WBO, Elko, Nev.
Ely	WBO, Ely, Nev.
Las Vegas	WBO, Box 1190, Las Vegas, Nev.
Reno	WBO, Box 1250, Reno, Nev.
Winnemucca	WBO, Winnemucca, Nev.
California (Section Center, San Francisco)	
Auburn	WBO, Box 446, Auburn, Calif.
Bakersfield	WBO, Route 1, Box 300, Bakersfield, Calif.
Beaumont	WBO, Beaumont, Calif.
Buffalo Springs	WBO, Buffalo Springs, Calif., % Catalina Air Transport Company, Box 1301, Avalon, Calif.
Burbank	WBAS, Lockheed Air Terminal, Burbank, Calif.
Burney	WBO, Burney Fire Hall, Burney, Calif.
Eureka	WBO, Eureka, Calif.
Fresno	WBO, Fresno 1, Calif.

CHAP. 6.2 BASIC HYDROLOGIC DATA
APPENDIX I SOURCES OF HYDROLOGIC DATA

Name of Office	Address
King City	WBO, Box K, King City, Calif.
Los Angeles (Regional Office)	Weather Bureau Regional Office, 1758 Post Office Building, Los Angeles 12, Calif.
Los Angeles, CO	WBO, 1758 Post Office Building, Los Angeles 12, Calif.
Los Angeles, AP	WBAS, Los Angeles Municipal Airport, Los Angeles 43, Calif.
Montague	WBO, Montague, Calif.
Mount Shasta	WBO, Mount Shasta, Calif.
Newhall	WBO, Box 544, Newhall, Calif.
Oakland	WBAS, Oakland 14, Calif.
Palmdale	WBO, Box 155, Palmdale, Calif.
Paso Robles	WBO, Box 307, Paso Robles, Calif.
Pomona	WBO, Pomona, Calif.
Red Bluff	WBO, Box 128, Red Bluff, Calif.
Sacramento, CO	WBO, Box 2002, Sacramento 9, Calif.
Sacramento, AP	WBAS, Sacramento Municipal Airport, Route 8, Sacramento, Calif.
Sandberg	WBO, Sandberg, Route 2, Lake Hughes, Calif.
San Diego	WBO, Lindbergh Field, San Diego 1, Calif.
San Francisco, CO	WBO, 50 Fulton Street, San Francisco 2, Calif.
San Francisco, AP	WBAS, San Francisco Airport, San Bruno, Calif.
San Pedro	WBO, San Pedro, Calif.
Santa Maria	WBO, Box 667, Santa Maria, Calif.
Territory of Hawaii	
Honolulu, T. H., CO	WBO, Box 3175, Honolulu 1, T. H.
Honolulu, T. H., AP	WBAS, John Rodgers Field, Honolulu, T. H.
Region 7 (Regional Office, Seattle, Washington)	
Montana (Section Center, Helena)	
Billings	WBO, Box 1338, Billings, Mont.
Butte	WBO, Box 1919, Butte, Mont.
Glasgow	WBO, Glasgow, Mont.
Great Falls	WBO, Box 1783, Great Falls, Mont.
Havre	WBO, Box 586, Havre, Mont.
Helena, CO	WBO, Box 1705, Helena, Mont.
Helena, AP	WBAS, Box 1705, Helena, Mont.
Kalispell	WBO, Kalispell, Mont.
Missoula, CO	WBO, Box 1406, Missoula, Mont.
Missoula, AP	WBAS, Box 1406, Missoula, Mont.
Idaho (Section Center, Boise)	
Boise	WBO, Box 1718, Boise, Idaho
*Burley	WBO, Box 528, Burley, Idaho
*Coeur d'Alene	WBO, Coeur d'Alene, Idaho
Lewiston	WBO, Lewiston, Idaho
Pocatello	WBO, Pocatello, Idaho
Oregon (Section Center, Portland)	
Baker, CO	WBO, Box 246, Baker, Oreg.
*Baker, AP	WBAS, % CAA Interstate A. C. S., Box 586, Baker, Oreg. (Send adm. corres. to city office.)

*Office has recently been discontinued.

CHAP. 6.2 BASIC HYDROLOGIC DATA
APPENDIX I SOURCES OF HYDROLOGIC DATA

Name of Office	Address
Burne	WBO, Burne, Oreg.
Eugene	WBO, Route 1, Eugene, Oreg.
Meacham	WBO, Meacham, Oreg.
Medford	WBO, Medford, Oreg.
Pendleton	WBO, Box 436, Pendleton, Oreg.
Portland, CO	WBO, 320 Custom House, Portland 9, Oreg.
Portland, AP	WBAS, Route 4, Box 801, Portland, Oreg.
Roseburg	WBO, Roseburg, Oreg.
Salem	WBO, Route 5, Salem, Oreg.
Sexton Summit	WBO, Box 283, Grants Pass, Oreg.
Siskiyou Summit	WBO, Route 1, Box 381, Ashland, Oreg.
Troutdale	WBO, Troutdale Airport, Troutdale, Oreg.
Washington (Section Center, Seattle)	
Ellensburg	WBO, Box 419, Ellensburg, Wash.
LaCrosse	WBO, LaCrosse, Wash.
North Head	WBO, North Head, Ilwaco, Wash.
Olympia	WBO, Route 5, Box 200, Municipal Airport, Olympia, Wash.
Port Townsend	WBO, Box 213, Port Townsend, Wash.
Seattle (Regional Office)	Weather Bureau Regional Office, 711 Federal Building, Seattle 4, Wash.
Seattle (Section Center)	WBO, 614 Federal Building, Seattle 4, Wash. (Send adm. corres. to Boeing Field.)
Seattle, AP	WBO, Boeing Field, Seattle 8, Wash.
Seattle-Tacoma Airport	WBO, Seattle-Tacoma Airport, 18279 South Pacific Highway, Seattle 88, Wash.
Spokane	WBO, Route 5, Spokane 15, Wash.
Stampede Pass	WBO, Stampede Pass, Lester, Wash.
Stevenson	WBO, Stevenson, Wash.
Tacoma	WBO, Tacoma 2, Wash.
Tatoosh Island	WBO, Tatoosh Island, Wash.
Walla Walla	WBO, Walla Walla, Wash.
Yakima, CO	WBO, Yakima, Wash.
Yakima, AP	WBAS, % CAA Interstate A. C. S., Yakima Municipal Airport, Route 7, Yakima, Wash. (Send adm. corres. to city office.)

FOREST SERVICE RESEARCH CENTERS AND FIELD STATIONS

Allegheny

1. Eastern Shore
2. Beltsville Res. Center
3. Standing Stone
4. Kane
5. Lebanon
6. Chenango
7. Finch-Pruyn
8. Hopkins Memorial
9. Gale River
10. Bartlett
11. Massabesic

Appalachian

13. Blacklands
14. Hofmann Forest
15. Santee

16. Tocca
17. Coweeta
18. Bent Creek
19. Fernow
20. Lee
21. Alaphaha

California

25. Devil Canyon
26. San Dimas
27. Kings River
28. San Joaquin
29. Stanislaus
30. Inst. of For. Genetics
31. Feather River
32. Black's Mountain
33. Shasta
34. Modoc
35. Swain Mountain
36. Yurok

Central States

40. Portsmouth
41. Southern Illinois
42. Sylamore
43. Hacker Creek

Intermountain

47. Great Basin
48. Desert
49. Ruby
50. Santa Rosa
51. Arrowrock
52. Boise Basin
53. Dubois
54. Logan
55. Wasatch

Lake States

60. Denbigh Dunes
61. Chippewa
62. Superior
63. Upper Peninsula
64. Nicolet
65. Lower Michigan
66. Upper Mississippi

Northern Rocky Mountain

70. Deception Creek
71. Priest River
72. Coram
73. Bernice
74. Miles City
75. Vigilante

Pacific Northwest

80. Wind River
81. Blue Mountain

82. Pringle Falls
83. Port Orford Cedar
84. Cascade Head
85. Starkey

Rocky Mountain

90. Fraser
91. Central Plains
92. Manitou Park
93. Fremont

Southern

95. San Jacinto
96. Palustris
97. Irons Fork
98. Crossett
99. Delta
100. Chewalla
101. Harrison
102. Hitchiti
103. Olustee

Southwestern

105. Santa Rita
106. Long Valley
107. Fort Valley
108. Sierra Ancha
109. Mt. Graham
110. Cloudcroft
111. Jornada

STATE AGRICULTURAL COLLEGES IN WESTERN STATES

College	Location
1. Colorado State College of Agriculture and Mechanical Arts	Ft. Collins, Colorado
2. Kansas State College of Agriculture and Applied Science	Manhattan, Kansas
3. Montana State College	Bozeman, Montana
4. N. Mexico College of Agriculture and Mechanical Arts	State College, N. Mex.
5. North Dakota Agricultural College	Fargo, N. Dak.
6. Oklahoma Agricultural and Mechanical College	Stillwater, Oklahoma
7. Oregon State College	Corvallis, Oregon
8. S. Dakota State College of Agriculture and Mechanical Arts	Brookings, S. Dak.
9. Texas Agricultural and Mechanical Arts College	College Station, Texas
10. Utah State Agricultural College	Logan, Utah
11. Washington State College	Pullman, Washington

STATE UNIVERSITIES IN WESTERN STATES

University	Location
1. Arizona, University of	Tucson, Arizona
2. California, (UCLA) University of	Los Angeles, California

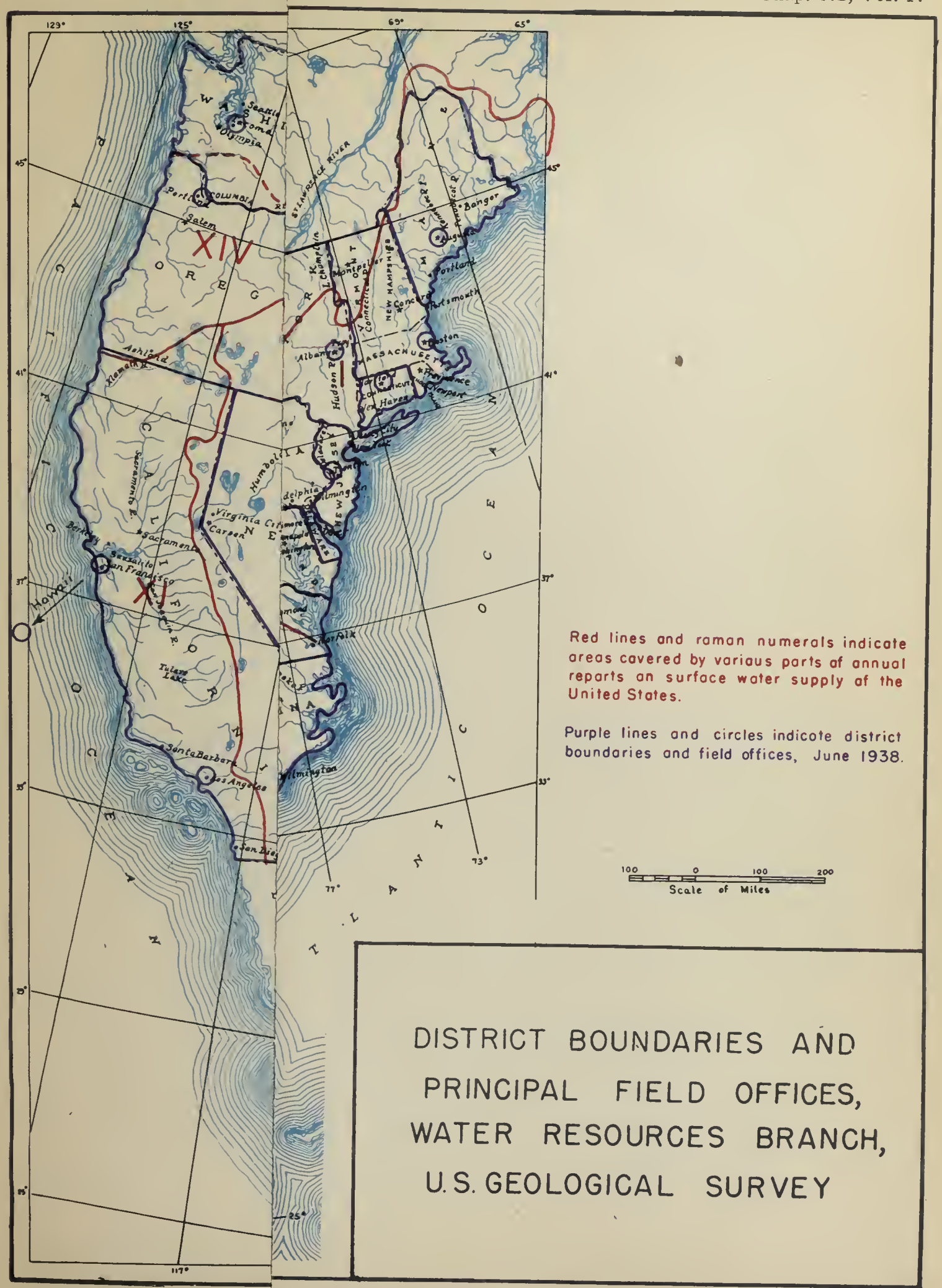
CHAP. 6.2 BASIC HYDROLOGIC DATA
APPENDIX I SOURCES OF HYDROLOGIC DATA

University	Location
3. California, (USC) University of Southern	Los Angeles, California
4. California, University of	Berkeley, California
5. California, University of	San Francisco, California
6. Colorado, University of	Boulder, Colorado
7. Idaho, University of	Moscow, Idaho
8. Kansas, University of	Lawrence, Kansas
9. Montana, University of	Missoula, Montana
10. Nebraska, University of	Lincoln, Nebraska
11. Nevada, University of	Reno, Nevada
12. New Mexico, University of	Albuquerque, New Mexico
13. North Dakota, University of	Grand Forks, North Dakota
14. Oklahoma, University of	Norman, Oklahoma
15. Oregon, University of	Eugene, Oregon
16. South Dakota, University of	Vermilion, South Dakota
17. Texas, University of	Austin, Texas
18. Utah, University of	Salt Lake City, Utah
19. Washington, University of	Seattle, Washington
20. Wyoming, University of	Laramie, Wyoming

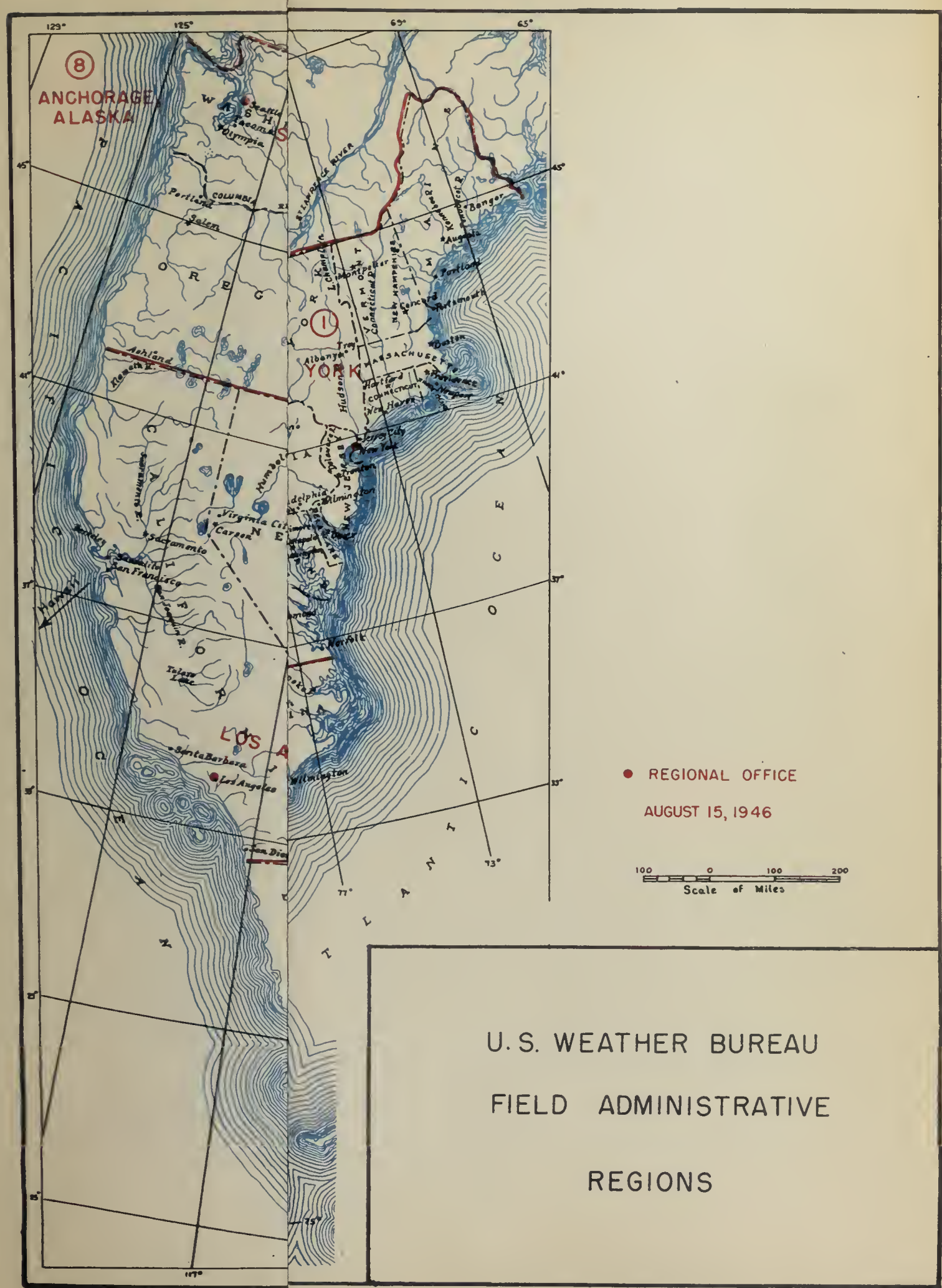
CHAP. 6.2 BASIC HYDROLOGIC DATA
APPENDIX I SOURCES OF HYDROLOGIC DATA

Geological Survey Water Supply Papers on Floods

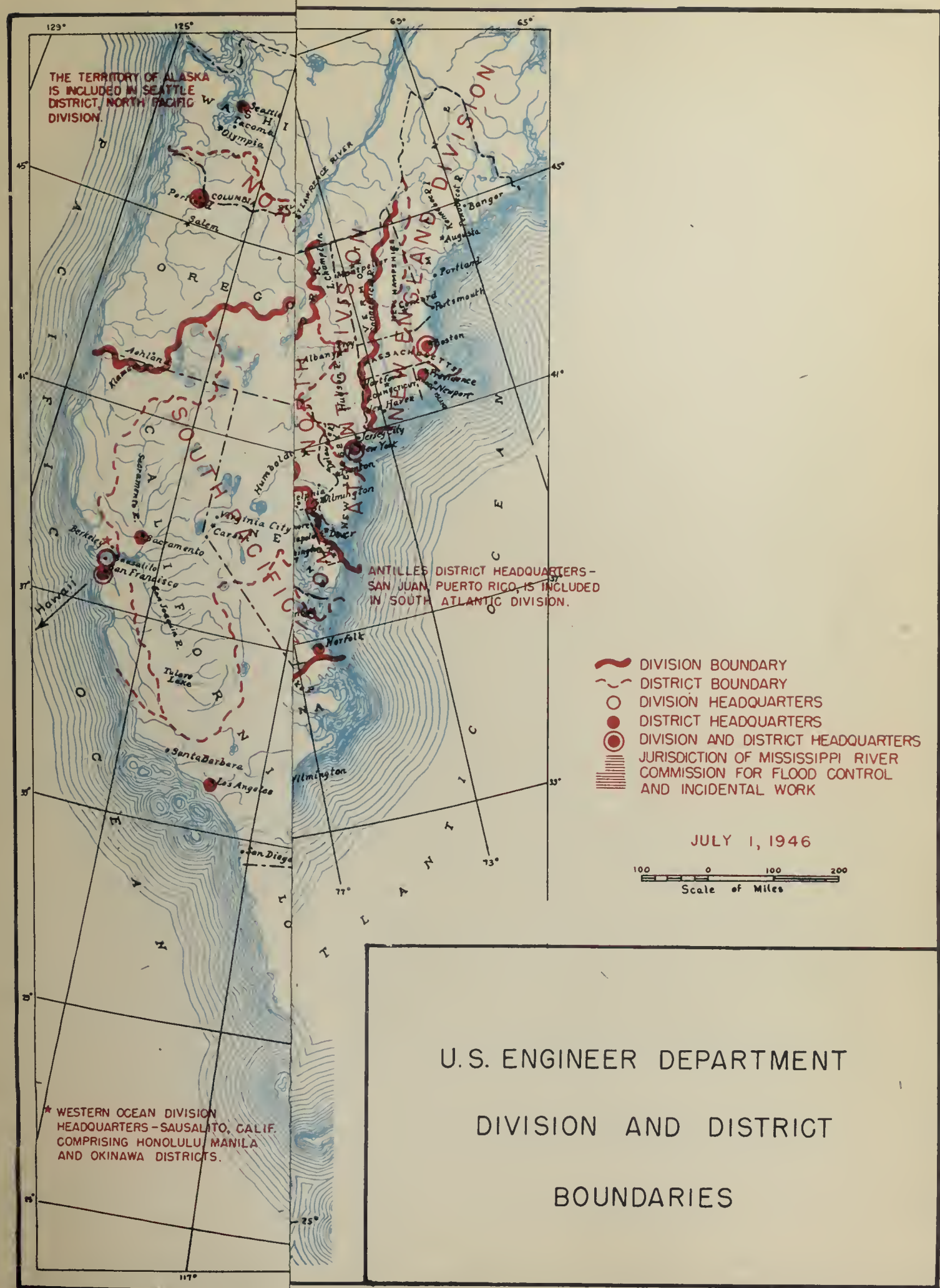
No.	Subject Matter Pertaining to Bureau of Reclamation Area
96	1903 Floods--Hepner, Oregon, Kansas and early Mississippi Valley.
147	1904 Floods--Sacramento River, Belle Fourche River, Kansas, Arizona, Canadian River, Pecos River, Rio Grande River and Denver Area.
162	1905 Floods--South Dakota, Purgatoire River, Pecos River, Hondo River, Rio Grande River, and Colorado River and Basin.
247	Surface Water Supply of the United States (Flood in the Arkansas Valley, Colorado, 10, 08).
269	Surface Water Supply of the United States (Flood in San Juan Valley, 9, 5 and 6, 09).
309	Surface Water Supply of the United States (Flood of October 1911, in the Region of the San Juan, San Miguel, and LaPlata Mountains).
426	1916 Floods--Southern California.
487	1921 Flood on Arkansas River around Pueblo, Colorado.
488	1921 Floods in Central Texas.
500-C	Characteristics of Runoff in Rocky Mountain Region.
520-G	1923--Floods on Big Horn and Powder River.
556	Water Power and Flood Control of Colorado River below Green River, Utah.
617	Upper Colorado River and its Utilization.
771	Floods in United States, Magnitude and Frequency.
772	Studies of Relations of Rainfall and Runoff in the United States.
796	(b) 1935 Flood on Republican and Kansas Rivers. (c) 1934 Flood in LaCanada Valley, California. (g) 1935 Floods in Texas.
816	1936--Floods in Texas.
842	Floods in New Mexico and on Canadian and Pecos Rivers in 1937.
843	December 1937--Floods in Northern California.
844	March 1938--Floods in Southern California.
847	Maximum Discharges at Stations through December 1937.
914	1938 and 1939--Floods in Texas.
967 (a)	1939--Flood in Colorado River Basin.
968-A	Flood Runoff in the Willamette Valley, Oregon.
968-B	Floods of the Puyallup and Chehalis River Basins, Washington.
994	Cloodburst Floods in Utah.
997	Floods in Colorado.
1046	Texas Floods of 1940.
1049	Summary of Records of Surface Waters at Stations on Tributaries in Lower Colorado River Basin 1888-1938.


Red lines and roman numerals indicate areas covered by various parts of annual reports on surface water supply of the United States.
Purple lines and circles indicate district boundaries and field offices, June 1938.
Scale of Miles
100 0 100 200
XIV
XV
DISTRICT BOUNDARIES AND PRINCIPAL FIELD OFFICES, WATER RESOURCES BRANCH, U.S. GEOLOGICAL SURVEY

Red lines and roman numerals indicate areas covered by various parts of annual reports on surface water supply of the United States.
Purple lines and circles indicate district boundaries and field offices, June 1938
Scale of Miles
DISTRICT BOUNDARIES AND PRINCIPAL FIELD OFFICES, WATER RESOURCES BRANCH, U.S. GEOLOGICAL SURVEY
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
XIII
XIV


8
ANCHORAGE
ALASKA
1
YORK
REGIONAL OFFICE
AUGUST 15, 1946
Scale of Miles
U. S. WEATHER BUREAU
FIELD ADMINISTRATIVE
REGIONS

8
ANCHORAGE
ALASKA
7
SEATTLE
1
NEW YORK
3
CHICAGO
5
KANSAS CITY
6
LOS ANGELES
4
FORT WORTH
2
ATLANTA
REGIONAL OFFICE
AUGUST 15, 1946
Scale of Miles
U.S. WEATHER BUREAU
FIELD ADMINISTRATIVE
REGIONS



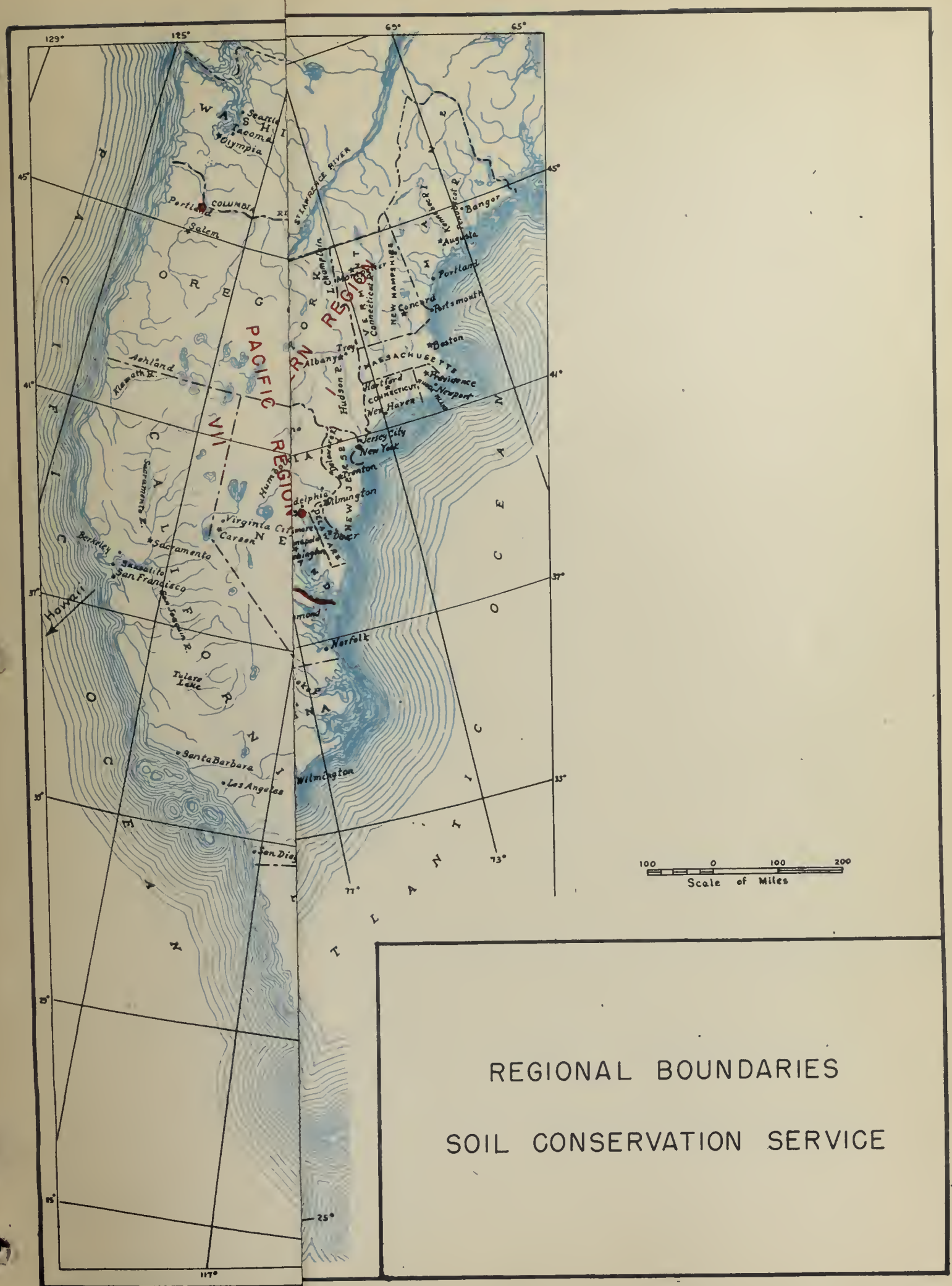
U.S. ENGINEER DEPARTMENT

DIVISION AND DISTRICT

BOUNDARIES

THE TERRITORY OF ALASKA IS INCLUDED IN SEATTLE DISTRICT, NORTH PACIFIC DIVISION.
NORTH PACIFIC DIVISION
SOUTH PACIFIC DIVISION
MISSOURI RIVER DIVISION
UPPER MISSISSIPPI VALLEY DIVISION
GREAT LAKES DIVISION
OHIO RIVER DIVISION
SOUTHWESTERN DIVISION
LOWER MISSISSIPPI VALLEY DIVISION
SOUTH ATLANTIC DIVISION
NEW ENGLAND DIVISION
MIDDLE ATLANTIC DIVISION
ANTILLES DISTRICT HEADQUARTERS - SAN JUAN, PUERTO RICO, IS INCLUDED IN SOUTH ATLANTIC DIVISION
WESTERN OCEAN DIVISION HEADQUARTERS - SAUSALITO, CALIF. COMPRISING HONOLULU, MANILA AND OKINAWA DISTRICTS.
DIVISION BOUNDARY
DISTRICT BOUNDARY
DIVISION HEADQUARTERS
DISTRICT HEADQUARTERS
DIVISION AND DISTRICT HEADQUARTERS
JURISDICTION OF MISSISSIPPI RIVER COMMISSION FOR FLOOD CONTROL AND INCIDENTAL WORK
JULY 1, 1946
Scale of Miles
U.S. ENGINEER DEPARTMENT
DIVISION AND DISTRICT
BOUNDARIES

12/30/47



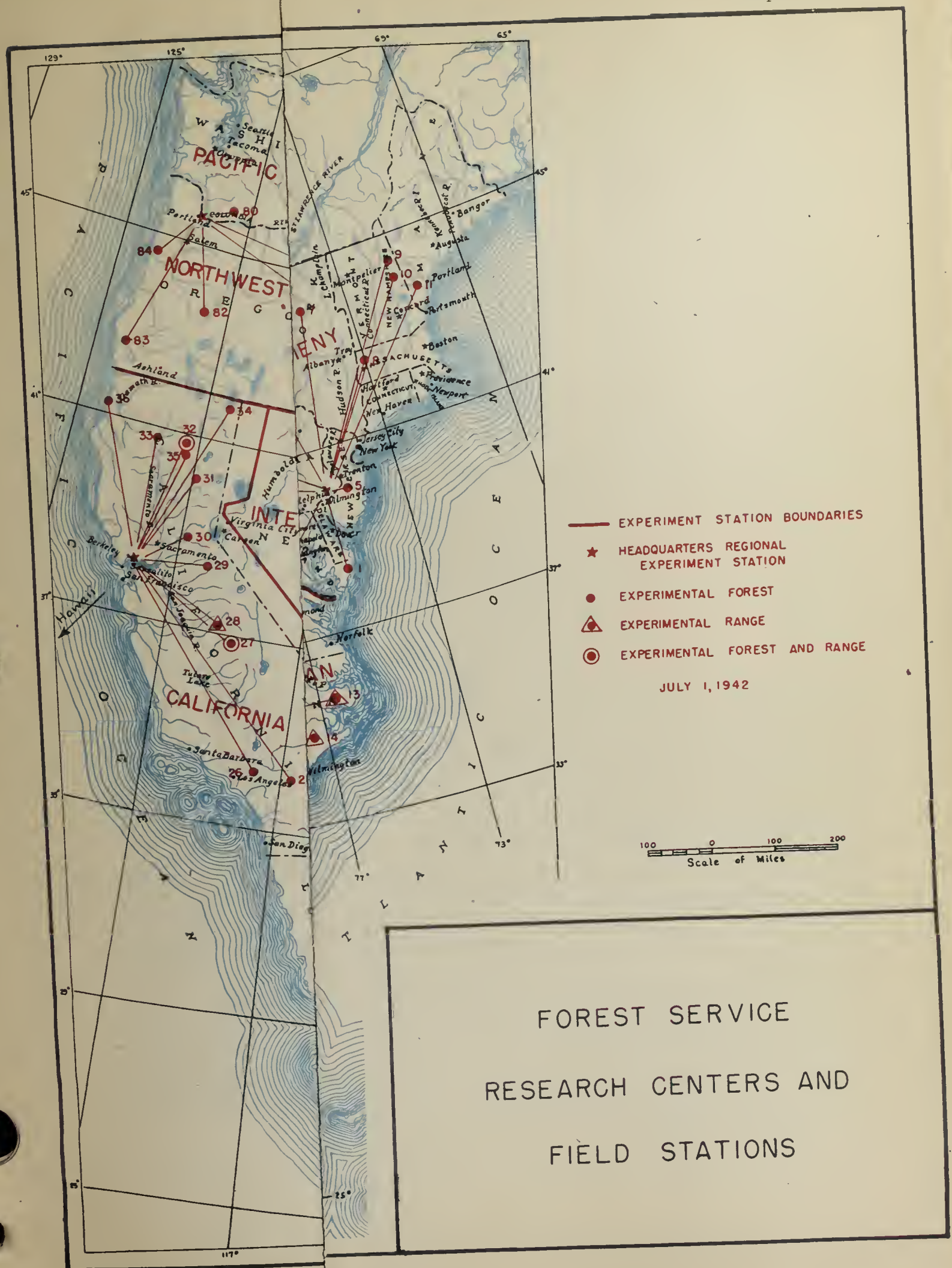
REGIONAL BOUNDARIES

SOIL CONSERVATION SERVICE

REGIONAL BOUNDARIES

SOIL CONSERVATION SERVICE

12/30/47



FOREST SERVICE RESEARCH CENTERS AND FIELD STATIONS

FOREST SERVICE

RESEARCH CENTERS AND

FIELD STATIONS

CHAP. 6.3 ENVELOPE CURVES

DEFINITION

.1 Envelope curves envelope plotted points representing maximum recorded flood peaks and volumes from comparable areas. These curves may be prepared by the methods discussed in the subsequent paragraphs.

USE

.2 Envelope curves are used in the spillway-design flood studies to obtain flood values for comparison with those derived by other methods. They are of value in illustrating the magnitude of floods that have occurred during the relatively short period of record on the streams in a general area, but it cannot be presumed that they fix the limit of future floods. Design flood values purporting to be the maximum probable should, in general, be higher than those obtained from envelope curves. For quick preliminary estimates of design floods, envelope curves are quite valuable. However, a design flood which is based solely on envelope curves should be used with precaution until a detailed study is made of flood potentialities.

LIMITATIONS

.3 In preparing envelope curves, the principal source of the flood data is United States Geological Survey Water Supply Papers which give the discharge values at a particular station and in most cases the drainage area above this point. However, seldom does a storm center over a sizable basin, such that the entire area above the gaging station contributes to runoff. If sufficient data are available, it is desirable to determine and use only the area which contributed to runoff. Often the intense portion of a storm will center on the divide between two basins with the result that neither basin has excessive runoff. On other occasions, the storm will have occurred on the upper part of a basin resulting in large discharges for this area but the stations downstream may indicate a decrease in discharge with increase in area because of channel storage and lack of complete areal coverage by the storm. In sparsely settled areas, local cloudbursts occur which result in excessive discharges, without being detected by a data-collecting agency. The above facts do not detract from the usefulness of envelope curves in spillway-design flood studies but are merely given to show the inherent weaknesses of such curves as indicators of the maximum probable flood.

MOUNTAINOUS AREA

.4 In some areas, particularly mountainous areas, snow melt contributes materially to runoff. For these areas, it is usually desirable to prepare two sets of envelope curves. One set of curves is used to show spring floods; the values (peaks and volumes) representing combined runoff from snow melt plus any rainfall that occurs during the snow-melt season. The points representing snow floods on the envelope curve of spring flood volume are usually computed for a period of 15 days. The other set of curves includes only rain floods which are not materially affected by runoff from snow melt.

SELECTION OF AREA

.5 The first step in the preparation of an envelope curve is the selection of a relatively homogeneous area or province, such as Central Plains, Great Basin, or Green River Basin. It is difficult to delineate general provinces for this purpose because the change in flood-producing characteristics from one area to another is generally gradual. It is usually advisable to overlap the boundaries on two adjacent provinces unless there is a distinct delineating physiographic feature such as a mountain range.

CENTRAL PLAINS AREA

.6 The Central Plains area, chosen as an example of the preparation and use of envelope curves, includes the greatest portion of Kansas and Nebraska, the southern part of South Dakota west of the Missouri River, southeastern Wyoming, and eastern Colorado. The area included in the Central Plains envelope curves is shown in Illustration 1. It was selected because, being a fairly well defined physiographic province, it has a similar type of topography in virtually all parts and is subject to the same general climate and the same type of storms.

PEAK DISCHARGE

A. The data shown in Illustration 2 was compiled from maximum flood discharges recorded in the Central Plains area.

(1) The primary source of data was the "United States Geological Survey Water Supply Paper 847," which is a summary of maximum recorded flood discharges through December 31, 1937, with a supplement including additions and changes through September 30, 1938. These data were

PEAK DISCHARGE (Cont.)

supplemented by records in later Water Supply Papers, and by records of the various state engineers, Bureau of Reclamation, and other agencies. Peak discharges from Illustration 2 were plotted versus their respective drainage-areas in Illustration 3. For ready references, gage locations corresponding to the higher plotted points are listed in Illustration 3.

(2) Each spillway-design flood study includes a description of the drainage basin under consideration. In drawing the envelope curves, areas represented by the control points should be compared with the area under consideration as to topography, soils, vegetation, slope, and any other pertinent factors affecting runoff. As an aid in comparing a basin under consideration with those represented by the control points on the envelope curves, use may be made of topographic, soils, and precipitation maps. For application to the 50-square-mile drainage-area above the Wray Damsite, for example, the highest points on either side of 50 square miles are considered. These points (Nos. 37 and 79) represent discharges from the South Fork Republican River, and Granada Creek, the drainage basins of which fit in general, the description of the North Fork Republican River Basin above the Wray Damsite. The envelope curve was drawn through points 37 and 79, as shown in Illustration 3, indicating a peak discharge of 34,000 cfs from a drainage-area of 50 square miles.

(3) Where sufficient data are available, it is well to include at this point in the flood study a discussion of the flood or floods which resulted in the discharge values used as control points. This discussion should include information on the average precipitation over the area contributing to the flood discharges used, average precipitation over the basin under study, and average precipitation over the latter basin with the storm shifted to center over this basin.

FLOOD VOLUME

B. The data in Illustration 4, a compilation of maximum recorded flood volumes of streams in the Central Plains area. The tabulated values were computed by adding the mean daily discharges in cubic feet per second for the duration of the flood of greatest volume which has been recorded at each of the gaging stations, and multiplying by the factor, 1.983, to convert the results to acre-feet. The period of time used in calculating the flood volume will vary for different floods, ranging from one day for cloudbursts to several days for a general storm.

(1) The United States Geological Survey Water Supply Papers comprise the principal source of data. As in the case of peak discharges, this source is supplemented by the records from other agencies. It should be noted that the flood which has the greatest volume may or may not be the same flood for which the maximum peak discharge was recorded. Some of the floods which resulted in large peak discharges do not appear in the flood volume data because only high watermarks were available for estimating the magnitudes. These were used to compute the maximum discharge by the slope-area method but are of little use in computing flood volumes. Flood volumes from the table were plotted versus their respective drainage areas in Illustration 5.

(2) Following the procedure outlined in Paragraph 6.3.6A(2), points 45 and 48 are the control points for the envelope curve of flood volume, shown in Illustration 5. Point 45 represents the maximum recorded flood volume from East Limestone Creek near Ionia, Kansas. Limestone Creek, in north central Kansas, is a tributary to the Solomon River, a short distance upstream from Beloit. Point 48 represents the maximum recorded flood volume from the Big Blue River at Beatrice, Nebraska. This stream drains a portion of southeastern Nebraska as shown in Illustration 1. The curve drawn through the above points indicates a flood volume of 9,400 acre-feet from a drainage-area of 50 square miles.

FUTURE DEVELOPMENT OF ENVELOPE CURVES

.7 Envelope curves of maximum recorded flood peaks and volumes can be prepared for other provinces having similar hydrologic and meteorologic character according to the procedure illustrated in the preceding paragraphs. It is the intention of the Hydrology Division to prepare a map on which the entire area of the 17 western states will be divided into such provinces. For each province, plates will be prepared (one for peaks and one for volumes) on which flood values of notable magnitude are plotted versus the respective drainage areas. Copies of the map will then be transmitted to the regional offices, with plates of flood peaks and volumes for the areas within the region concerned. The plates may then be used to derive envelope curves for application to specific areas. However, until the above-mentioned map and plates are prepared, it will be necessary for each region to develop envelope curves for its specific needs.

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2. United States Geological Survey, Water-Supply Paper 487.
3. United States Geological Survey, Water-Supply Paper 796-B.
4. United States Geological Survey, Water-Supply Papers, Part 6.
5. United States Geological Survey, Water-Supply Papers, Part 7.
6. Creager, Justin and Hinds, Engineering for Dams, Vol. 1, John Wiley and Sons.

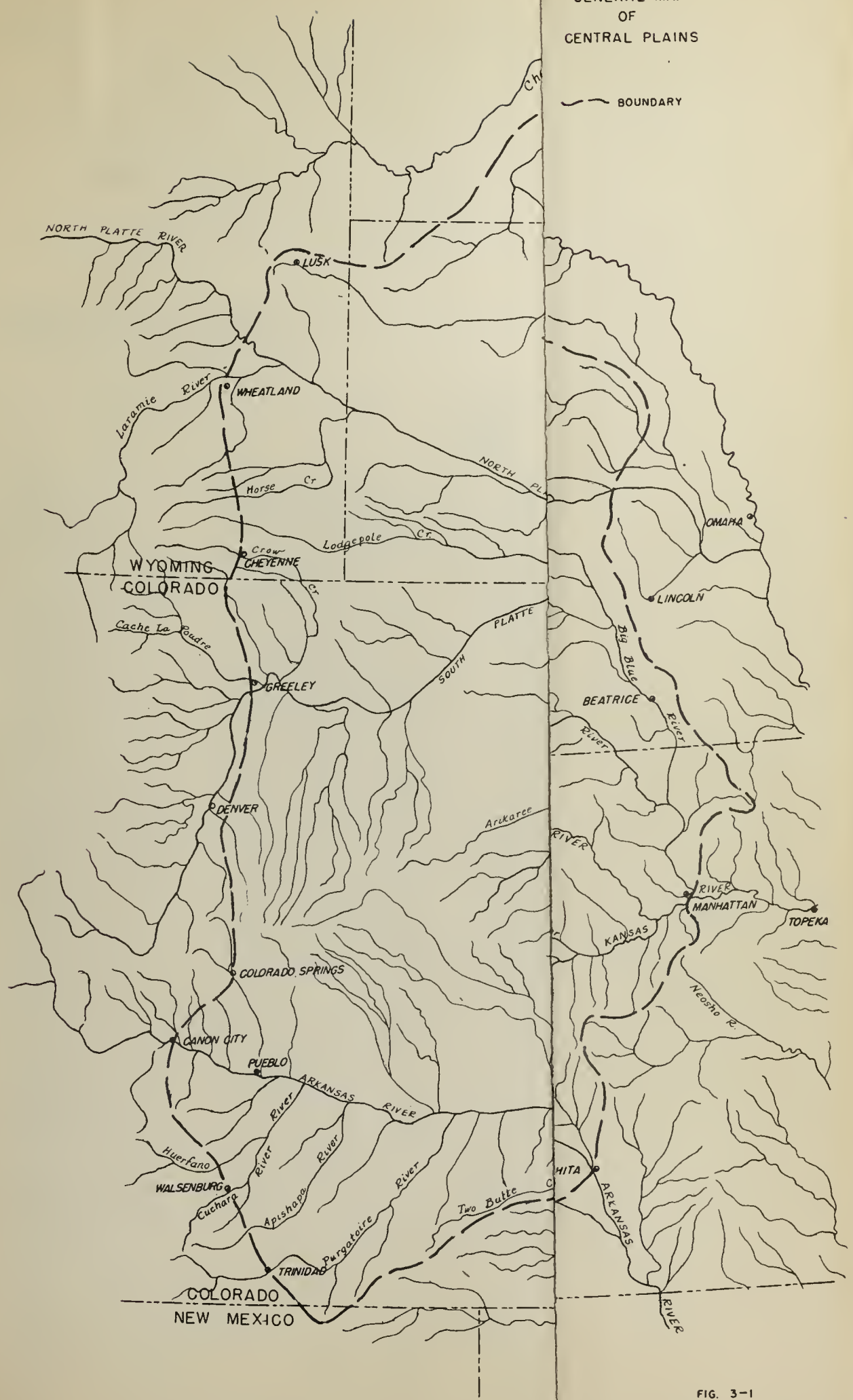
GENERAL MAP
OF
CENTRAL PLAINS
BOUNDARY
NORTH PLATTE RIVER
LUSK
WHEATLAND
Laramie River
Horse Cr
NORTH PL
Lodgepole Cr
Crow Cr
CHEYENNE
WYOMING
COLORADO
Cache La Poudre
GREELEY
SOUTH PLATTE
DENVER
Arikaree
RIVER
OMAHA
LINCOLN
Big Blue River
BEATRICE
RIVER
MANHATTAN
TOPEKA
KANSAS
Neosho R.
COLORADO SPRINGS
CANON CITY
PUEBLO
ARKANSAS RIVER
Huerfano
WALSENBURG
Cuchara River
Apishapa River
Purgatoire River
TRINIDAD
Two Butte C
HITA
ARKANSAS
RIVER
COLORADO
NEW MEXICO

FIG. 3-1

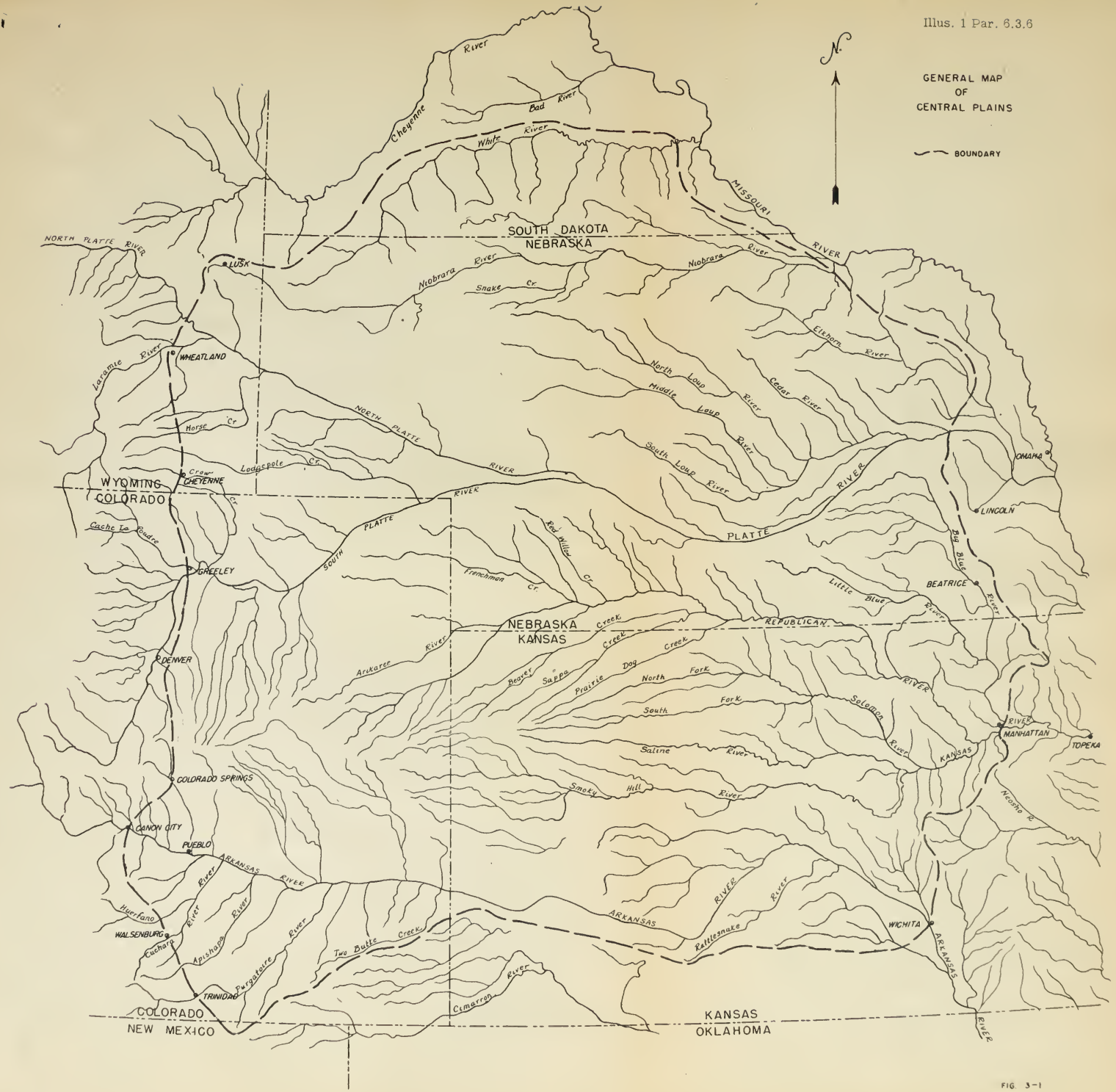
GENERAL MAP
OF
CENTRAL PLAINS
BOUNDARY
N.
SOUTH DAKOTA
NEBRASKA
WYOMING
COLORADO
NEBRASKA
KANSAS
COLORADO
NEW MEXICO
KANSAS
OKLAHOMA
NORTH PLATTE RIVER
LUSK
WHEATLAND
Laramie River
Horse Cr.
Crow
CHEYENNE
Lodgepole Cr.
Cache la Poudre
GREELEY
DENVER
COLORADO SPRINGS
CANON CITY
PUEBLO
WALSENBURG
TRINIDAD
Huerfano
Cucharas River
Apishapa River
Purgatoire River
ARKANSAS RIVER
Two Butte Creek
Cimarron River
Cheyenne
Bad River
White River
Niobrara River
Snake Cr.
MISSOURI RIVER
Elkhorn River
North Loup River
Middle Loup River
South Loup River
Cedar River
OMAHA
LINCOLN
NORTH PLATTE RIVER
SOUTH PLATTE RIVER
PLATTE RIVER
Red Willow Cr.
Frenchman Cr.
Big Blue River
Little Blue River
BEATRICE
REPUBLICAN RIVER
Arikaree River
Beaver Creek
Sappa Creek
Prairie Dog Creek
North Fork
South Fork
Solomon River
Saline River
Smoky Hill River
KANSAS RIVER
MANHATTAN
TOPEKA
Neosho R.
ARKANSAS RIVER
Rattlesnake River
WICHITA
ARKANSAS RIVER

FIG. 3-1

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BRANCH OF PROJECT PLANNING
HYDROLOGY DIVISION

COMPUTED BY _____
DATE _____
CHECKED BY _____
DATE _____

ENVELOPE CURVE DATA FOR Maximum
Recorded Peak Discharges--Central Plains

NO.	STREAM	LOCATION	DRAINAGE AREA SQUARE MILES	DATE Month, Day, Year	DISCHARGE IN C.F.S.
1	White R.	at Crawford, Nebr.	295	8-2-40	1,170
2	White R.	nr. Chadron, Nebr.	750	5-12-42	3,690
3	White R.	nr. Interior, S.D.	4,120	3-8-05	16,500
4	White R.	nr. Kadoka, S.D.	5,000	6-4-42	24,000
5	White R.	nr. Oacoma, S.D.	10,200	5-8-42	35,300
6	S.Fk. White R.	nr. White R., S.D.	1,390	5-6-32	3,840
7	Niobrara R.	at Dunlap, Nebr.	1,550	9-4-37	2,890
8	Niobrara R.	nr. Spencer, Nebr.	10,800	6-14-43	21,500
9	Rawhide Creek	nr. Lingle, Wyo.	510	7-12-41	3,860
10	Crow Creek	nr. Silvercrown, Wyo.	39	7-2-29	3,600
11	Crow Creek	nr. Cheyenne, Wyo.	113	7-2-29	8,200
12	Horse Creek	nr. Lyman, Nebr.	1,860	5-19-38	1,970
13	Pumpkin Creek	nr. Bridgeport, Nebr.	1,080	3-9-39	864
14	Blue Creek	nr. Lewellen, Nebr.	267	5-20-38	720
15	Birdwood Creek	nr. Hershey, Nebr.	286	4-24-35	830
16	North Platte R.	at Mitchell, Nebr.	24,300	6-17-21	23,600
17	Middle Loup R.	at St. Paul, Nebr.	7,320	6-15-43	36,000
18	Loup R.	at Columbus, Nebr.	14,200	6-6-96	70,000
19	North Loup R.	nr. St. Paul, Nebr.	4,040	6-6-96	90,000
20	Elkhorn R.	at Neligh, Nebr.	1,740	6-3-35	2,150
21	Elkhorn R.	at Arlington, Nebr.	5,980	7-17-15	12,700
22	Elkhorn R.	at Waterloo, Nebr.	6,380	6-7-40	22,900
23	Arikaree R.	at Cope, Colo.	690	5-31-35	25,000
24	Arikaree R.	nr. Idalia, Colo.	1,190	5-31-35	54,000
25	Arikaree R.	at Haigler, Nebr.	1,600	5-31-35	50,000
26	Republican R.	at Max, Nebr.	*5,840	5-31-35	190,000
27	Republican R.	at Culbertson, Nebr.	*8,700	5-31-35	200,000
28	Republican R.	at McCook, Nebr.	*10,100	5-31-35	245,000
29	Republican R.	at Cambridge, Nebr.	*12,300	5-31-35	280,000
30	Republican R.	nr. Bloomington, Nebr.	*19,000	6-1-35	260,000
31	Republican R.	nr. Hardy, Nebr.	*20,500	6-2-35	225,000
32	Republican R.	at Scandia, Kans.	22,930	6-2-35	215,000
33	Republican R.	at Clay Center, Kans.	24,570	6-3-35	195,000
34	Republican R.	at Junction City, Kan.	24,960	6-3-35	168,000
35	N.Fk. Republican R.	at Colo-Nebr. line	395	9-3-40	1,220
36	S.Fk. Republican R.	at Newton, Colo.	1,270	5-31-35	103,000
37	S.Fk. Republican R.	below St. Francis, Kan.	2,200	5-31-35	150,000
38	S.Fk. Republican R.	nr. Bankleman, Nebr.	2,550	5-31-35	150,000
39	Medicine Creek	nr. Cambridge, Nebr.	*722	5-31-35	35,000 est

HD-7 * Excludes sand-hill area that does not contribute to surface runoff.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BRANCH OF PROJECT PLANNING
HYDROLOGY DIVISION

COMPUTED BY _____
DATE _____
CHECKED BY _____
DATE _____

ENVELOPE CURVE DATA FOR Maximum
Recorded Peak Discharge--Central Plaine

NO.	STREAM	LOCATION	DRAINAGE AREA SQUARE MILES	DATE Month, Day, Year	DISCHARGE IN C.F.S.
40	Red Willow Creek	nr. Red Willow, Nebr.	880	6-2-41	4,610
41	Prairie Dog Creek	nr. Woodruff, Kans.	900	7-25-29	2,830
42	Frenchman Creek	nr. Champion, Nebr	* 558	6-6-40	7,220
43	Frenchman Creek	below Champion, Nebr.	* 570	6-7-40	11,600
44	Frenchman Creek	at Culbertson, Nebr.	* 1,554	5-31-35	15,000
45	Frenchman Creek	nr. Hamlet, Nebr.	* 950	6-7-40	2,400
46	W. Buffalo Creek	nr. Jewell, Kans.	15.2	9-1-35	3,520
47	Smoky Hill R.	at Ellsworth, Kans.	7,580	6-1-38	61,000
48	Smoky Hill R.	at Enterprise, Kans.	19,200	5- -03	90,000
49	Saline R.	nr. Wilson, Kans.	1,900	7- -28	25,700
50	Saline R.	nr. Salina, Kans.	3,311	5-30-03	27,000
51	S.Fk. Solomon R.	at Alton, Kans.	1,720	9-19-19	9,340
52	Solomon R.	at Beloit, Kans.	5,430	6-3-35	37,800
53	Solomon R.	at Niles, Kans.	6,770	6-3-03	41,000
54	N.Fk.Solomon R.	at Kirwin, Kans.	1,290	9-18-19	15,500
55	E.Limestone Creek	nr. Ionia, Kans.	24	5-28-35	3,920
56	E.Limestone Creek	at Ionia, Kans.	55	6-1-35	7,250
57	Elm Creek	nr. Ionia, Kans.	23	9-1-35	4,490
58	Big Blue R.	at Beatrice, Nebr.	3,363	7-23-11	22,400
59	Big Blue R.	at Barnston, Nebr.	4,350	6-9-41	57,700
60	Big Blue R.	at Randolph, Kans.	9,100	6-10-41	98,000
61	Big Blue R.	at Manhattan, Kans.	9,600	5-31-03	98,000
62	Little Blue R.	nr. Endicott, Nebr.	2,590	6-9-41	26,800
63	Little Blue R.	at Waterville, Kans.	3,440	6-10-41	50,400
64	Arkansas R.	nr. Pueblo, Colo.	** 1,640	6-3-21	103,000
65	Arkansas R.	at La Junta, Colo.	** 9,110	6-4-21	200,000
66	Ninnescah R.	nr. Peck, Kans.	2,092	4-23-44	19,700
67	St. Charles R.	nr. Pueblo, Colo.	464	6-3-21	56,000
68	Huerfano R.	nr. Mustang, Colo.	800	8-14-42	26,000
69	Huerfano R.	nr. Undercliffe, Colo.	1,710	7-28-36	26,600
70	Apishapa R.	nr. Fowler, Colo.	1,130	8-15-42	14,700
71	Purgatoire R.	nr. Higbee, Colo.	2,900	9-15-34	64,500
72	Fountain Creek	nr. Fountain, Colo.	676	5-28-40	22,100
73	Fountain Creek	at Pueblo, Colo.	932	6-4-21	34,000
74	Rock Creek	at Pueblo, Colo.	59	6-3-21	53,900
75	Cameron Arroyo	at Pueblo, Colo.	7.3	6-3-21	13,900
76	Esteen Arroyo	at Pueblo, Colo.	7.8	6-3-21	9,100
77	Blue Ribbon Creek	at Pueblo, Colo.	6.7	6-3-21	9,100
78	Unnamed Arroyo	at Pueblo, Colo.	1.8	6-3-21	1,900

*See note, sheet 1.
**Excludes area above Canon City which contributed little to the flood

HD-7

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BRANCH OF PROJECT PLANNING
HYDROLOGY DIVISION

COMPUTED BY _____
DATE _____
CHECKED BY _____
DATE _____

ENVELOPE CURVE DATA FOR Maximum
Recorded Peak Discharge—Central Plains

NO.	STREAM	LOCATION	DRAINAGE AREA SQUARE MILES	DATE Month, Day, Year	DISCHARGE IN C.F.S.
79	Granada Creek	nr. Granada, Colo.	40	7-11-35	31,000
80	Two Butte Creek	at mouth of cr. Colo.	900	10- -08	35,000
81	Wild Horse Creek	nr. Holly, Colo.	155	8-28-35	22,000
82	Pawnee R.	nr. Larned, Kans.	2,300	5-28-35	20,000
83	Cow Creek	nr. Lyons, Kans.	501	10-20-41	12,400
84	Little Arkansas R.	at Valley Center, Kan.	1,316	4-23-44	26,300

HD-7

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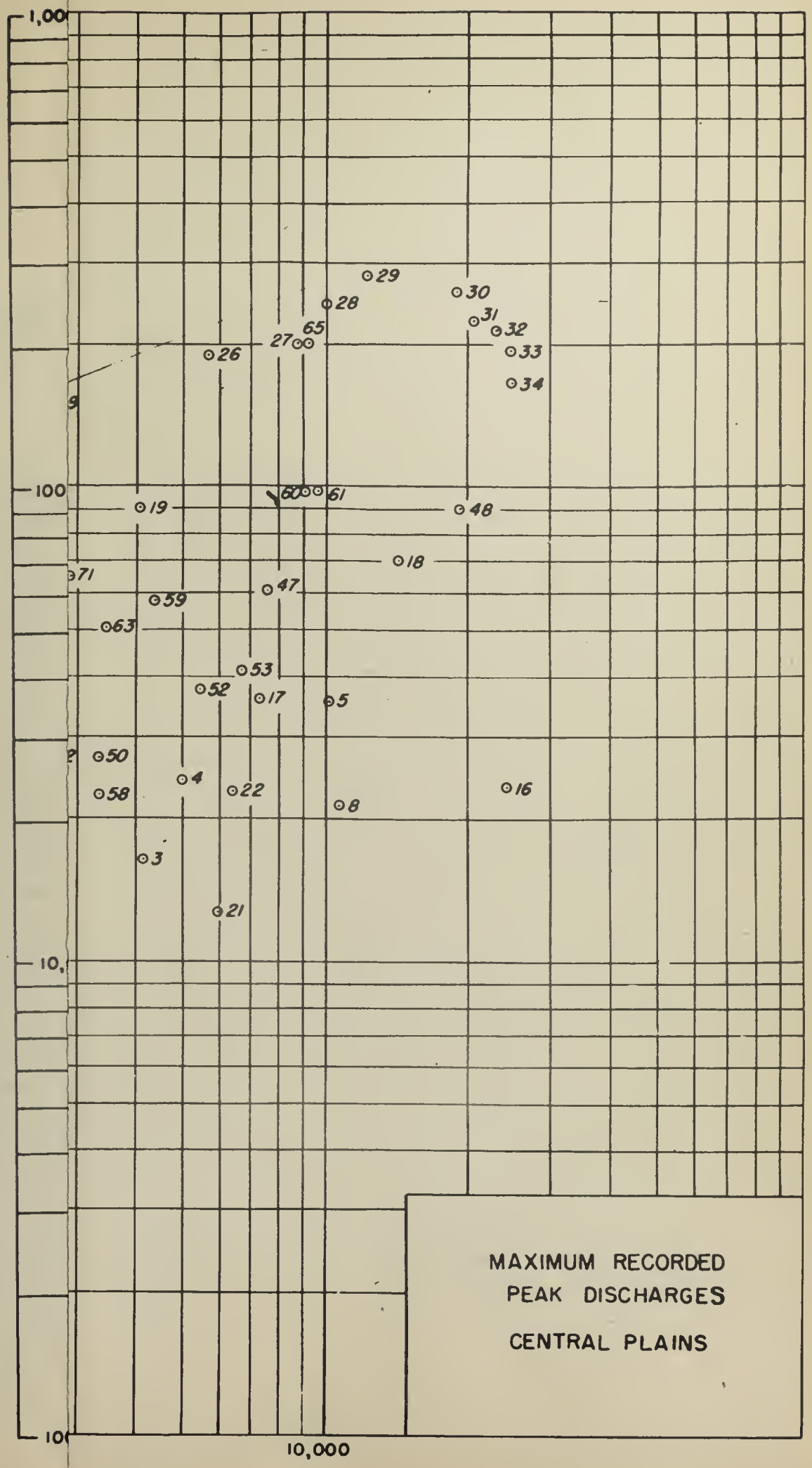
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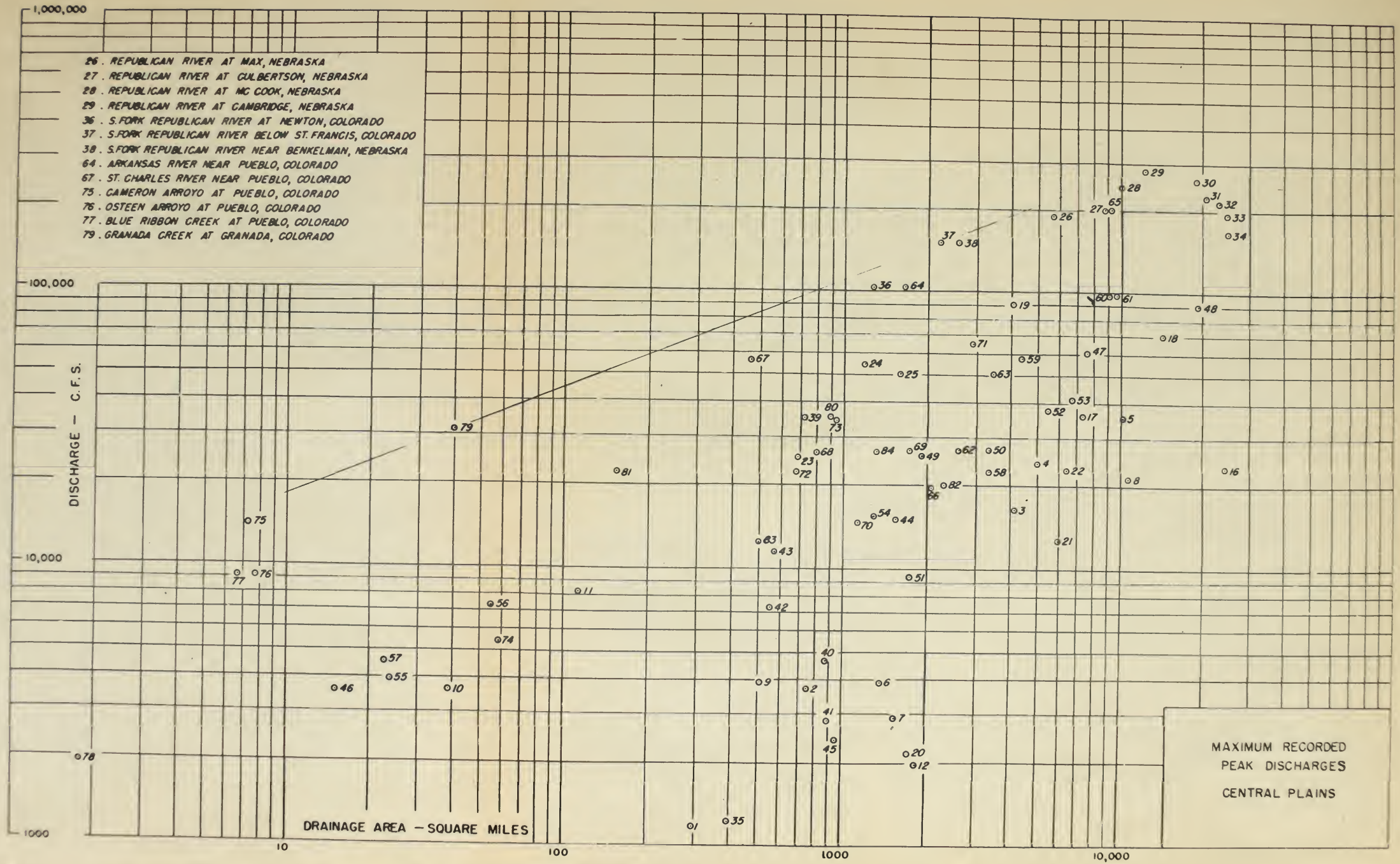
16
58
8
3
21
MAXIMUM RECORDED
PEAK DISCHARGES
CENTRAL PLAINS


26 . REPUBLICAN RIVER AT MAX, NEBRASKA
27 . REPUBLICAN RIVER AT GULBERTSON, NEBRASKA
28 . REPUBLICAN RIVER AT MC COOK, NEBRASKA
29 . REPUBLICAN RIVER AT CAMBRIDGE, NEBRASKA
36 . S. FORK REPUBLICAN RIVER AT NEWTON, COLORADO
37 . S. FORK REPUBLICAN RIVER BELOW ST. FRANCIS, COLORADO
38 . S. FORK REPUBLICAN RIVER NEAR BENKELMAN, NEBRASKA
64 . ARKANSAS RIVER NEAR PUEBLO, COLORADO
67 . ST. CHARLES RIVER NEAR PUEBLO, COLORADO
75 . CAMERON ARROYO AT PUEBLO, COLORADO
76 . OSTEEN ARROYO AT PUEBLO, COLORADO
77 . BLUE RIBBON CREEK AT PUEBLO, COLORADO
79 . GRANADA CREEK AT GRANADA, COLORADO
1,000,000
100,000
10,000
1000
DISCHARGE — C.F.S.
10
100
1000
10,000
DRAINAGE AREA — SQUARE MILES
MAXIMUM RECORDED
PEAK DISCHARGES
CENTRAL PLAINS

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BRANCH OF PROJECT PLANNING
HYDROLOGY DIVISION

ENVELOPE CURVE DATA FOR Maximum
Recorded Flood Volume--Central Plains

COMPUTED BY _____
DATE _____
CHECKED BY _____
DATE _____

NO.	STREAM	LOCATION	DRAINAGE AREA SQUARE MILES	DATE Month, Day, Year	VOLUME IN ACRE FEET
1	White R.	at Crawford, Nebr.	295	5-11-15-42	4,000
2	White R.	nr. Chadron, Nebr.	750	5-11-15-42	13,300
3	White R.	nr. Interior, S. D.	4,120	5-12-19-42	130,000
4	White R.	Oacoma, S. D.	10,200	5-5-10-42	260,000
5	S.Fk. White R.	nr. White R. S. D.	1,390	5-6-14-32	13,600
6	Niobrara R.	at Dunlap, Nebr.	1,550	9-4-7-37	3,200
7	Niobrara R.	nr. Spencer, Nebr.	10,800	5-12-21-42	111,000
8	Rawhide Creek	nr. Lingle, Wyo.	510	7-12-22-41	4,900
9	Cherry Creek	nr. Melvin, Colo.	369	4-19-5-5-42	14,600
10	Horse Creek	nr. Lyman, Nebr.	1,860	6-8-14-41	3,740
11	Pumpkin Creek	nr. Bridgeport, Nebr.	1,080	8-7-13-39	1,720
12	Blue Creek	nr. Lewellen, Nebr.	267	5-17-25-38	2,060
13	Birdwood Creek	nr. Hershey, Nebr.	286	5-26-6-1-35	3,270
14	North Platte R.	at Mitchell, Nebr.	24,300	6-8-27-21	626,000
15	Middle Loup R.	at St. Paul, Nebr.	7,320	8-1-15-41	127,000
16	Loup R.	at Columbia, Nebr.	14,200	8-1-15-36	321,000
17	North Loup R.	nr. St. Paul, Nebr.	4,040	2-27-3-13-36	119,000
18	Elkhorn R.	at Neligh, Nebr.	1,740	6-1-8-35	23,400
19	Elkhorn R.	at Arlington, Nebr.	5,980	7-11-25-15	210,000
20	Elkhorn R.	at Waterloo, Nebr.	6,380	6-4-18-40	232,000
21	Arikaree R.	at Haigler, Nebr.	1,600	5-20-6-10-35	67,000
22	Republican R.	at Max, Nebr.	*5,640	5-28-6-10-35	312,000
23	Republican R.	at Culbertson, Nebr.	*8,700	5-28-6-10-35	345,000
24	Republican R.	nr. Bloomington, Nebr.	*19,000	5-27-6-9-35	478,000
25	Republican R.	nr. Hardy, Nebr.	*20,500	5-28-6-11-35	485,000
26	Republican R.	at Scandia, Kans.	22,930	5-28-6-10-35	546,000
27	Republican R.	at Clay Center, Kans.	24,570	5-28-6-10-35	518,000
28	N.Fk. Republican R.	at Colo.-Nebr. line	395	5-31-6-5-35	2,200
29	S.Fk. Republican R.	at Newton, Colo.	1,270	5- -35	103,000(est.)
30	Medicine Creek	nr. Cambridge, Nebr.	* 722	5- -35	65,000(est.)
31	Red Willow Creek	nr. Red Willow, Nebr.	880	6-6-11-41	4,250
32	Prairie Dog Creek	nr. Woodruff, Kans.	900	7-24-30-29	12,000
33	Frenchman Creek	below Champion, Nebr.	* 570	6-6-10-40	14,200
34	Frenchman Creek	nr. Hamlet, Nebr	* 950	6-6-12-40	14,200
35	Frenchman Creek	at Culbertson, Nebr.	*1,554	6-7-12-40	16,300
36	West Buffalo Creek	nr. Jewell, Kans.	15.2	9-1-35	1,400
37	Smoky Hill R.	at Ellsworth, Kans.	7,580	5-30-6-10-38	177,000
38	Smoky Hill R.	at Enterprise, Kans.	19,200	6-21-7-8-35	438,000
39	Saline R.	nr. Wilson, Kans.	1,900	5-27-6-5-35	68,000

HD-7 *Excludes sandhill area that does not contribute to surface runoff.

12/30/47

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BRANCH OF PROJECT PLANNING
HYDROLOGY DIVISION

COMPUTED BY _____
DATE _____
CHECKED BY _____
DATE _____

ENVELOPE CURVE DATA FOR Maximum
Recorded Flood Volumes--Central Plains

NO.	STREAM	LOCATION	DRAINAGE AREA SQUARE MILES	DATE Month, Day, Year	VOLUME IN ACRE FEET
40	Saline R.	at Tescott, Kans.	2,800	7-30-8-19-28	136,000
41	S.Fk.Solomon R.	at Alton, Kans.	1,720	9-18-28-19	27,400
42	Solomon R.	at Beloit, Kans.	5,430	6-3-22-41	224,000
43	Solomon R.	at Niles, Kans.	6,770	5-30-6-10-35	277,000
44	N.Fk. Solomon R.	at Kirwin, Kans.	1,290	9-18-27-19	48,000
45	East Limestone Creek	nr. Ionia, Kans.	24	5-27-6-2-35	4,600
46	East Limestone Creek	at Ionia, Kans.	55	5-27-6-2-35	9,200
47	Elm Creek	nr. Ionia, Kans.	23	5-27-6-2-35	4,150
48	Big Blue R.	at Beatrice, Nebr.	3,363	3-19-4-8-12	517,000
49	Big Blue R.	at Barnston, Nebr.	4,350	6-6-15-41	208,000
50	Big Blue R.	at Randolph, Kans.	9,100	6-8-17-41	479,000
51	Little Blue R.	nr. Endicott, Nebr.	2,590	6-6-15-41	118,000
52	Little Blue R.	at Waterville, Kans.	3,440	6-8-18-41	227,000
53	Arkansas R.	at Pueblo, Colo.	** 1,640	6-2-9-21	162,000
54	Arkansas R.	at La Junta, Colo.	12,200	6-6-25-03	186,000
55	St. Charles, R.	at mouth of R., Colo.	482	6-2-5-21	60,000
56	Huerfano R.	nr. Mustang, Colo.	800	3-14-16-42	3,900
57	Huerfano R.	nr. Undercliffe, Colo.	1,702	6-7-11-38	12,200
58	Apishapa R.	nr. Fowler, Colo.	1,130	3-21-31-23	32,000
59	Purgatoire R.	nr. Higbee, Colo.	2,900	9- -34	22,800
60	Fountain Creek	nr. Fountain, Colo.	676	5-27-31-40	5,500
61	Granada Creek	nr. Granada, Colo.	40	7- -35	6,400
62	Wild Horse Creek	nr. Holly, Colo.	155	8- -35	15,500
63	Pawnee R.	nr. Larned, Kans.	2,300	5-21-6-1-35	72,500
64	Cow Creek	nr. Lyons, Kans.	501	10-19-27-41	39,500
65	Little Arkansas R.	at Valley Center, Kan.	1,332	4-21-29-44	186,000
66	Ninnescah R.	nr. Peck, Kans.	2,092	4-21-29-44	122,000

**Excludes area above Canon City which contributed little to this flood.

HD-7

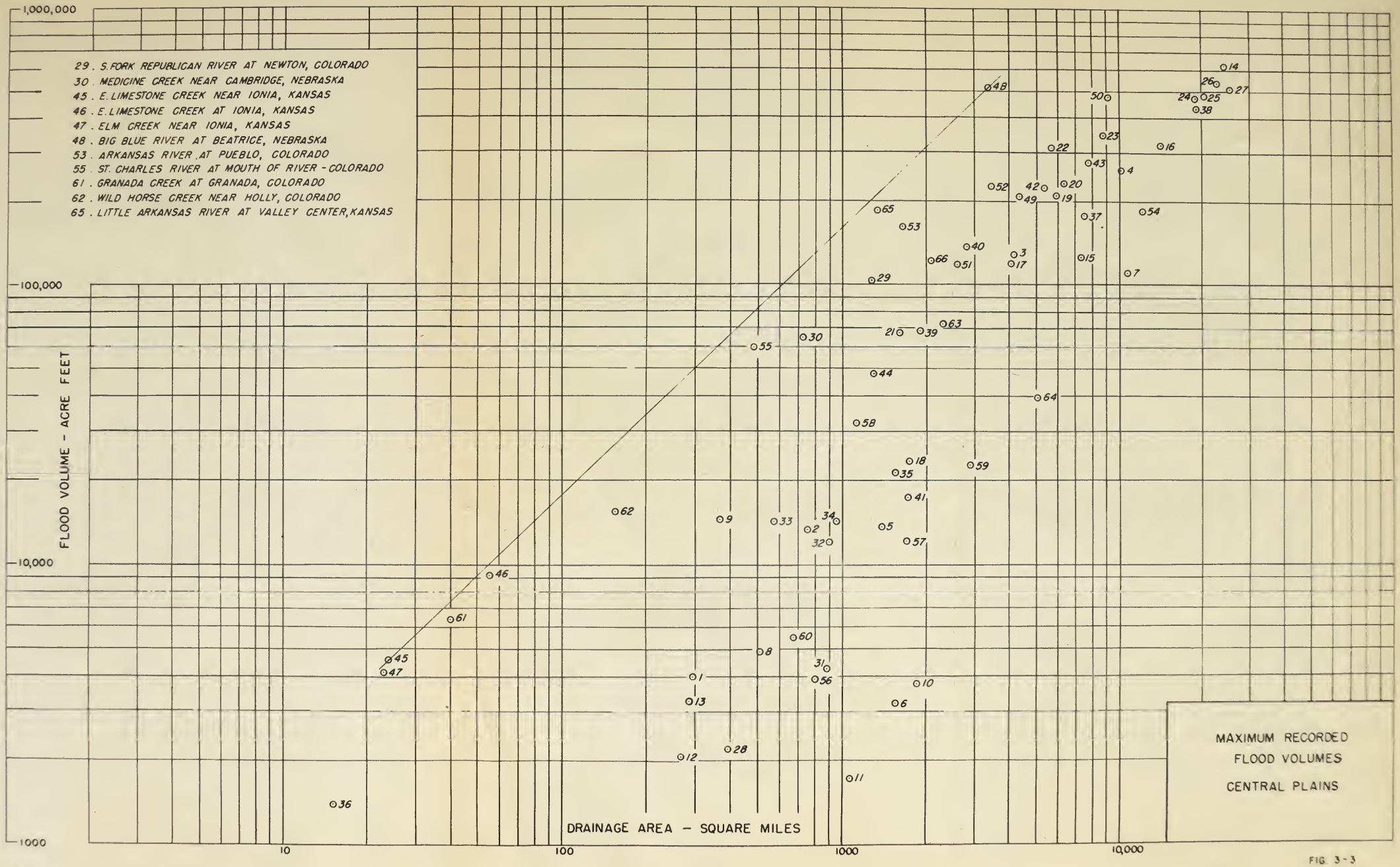

29. S. FORK REPUBLICAN RIVER AT NEWTON, COLORADO
30. MEDICINE CREEK NEAR CAMBRIDGE, NEBRASKA
45. E. LIMESTONE CREEK NEAR IONIA, KANSAS
46. E. LIMESTONE CREEK AT IONIA, KANSAS
47. ELM CREEK NEAR IONIA, KANSAS
48. BIG BLUE RIVER AT BEATRICE, NEBRASKA
53. ARKANSAS RIVER AT PUEBLO, COLORADO
55. ST. CHARLES RIVER AT MOUTH OF RIVER - COLORADO
61. GRANADA CREEK AT GRANADA, COLORADO
62. WILD HORSE CREEK NEAR HOLLY, COLORADO
65. LITTLE ARKANSAS RIVER AT VALLEY CENTER, KANSAS
1,000,000
100,000
10,000
1000
FLOOD VOLUME - ACRE FEET
10
100
1000
10,000
DRAINAGE AREA - SQUARE MILES
MAXIMUM RECORDED
FLOOD VOLUMES
CENTRAL PLAINS

FIG. 3-3